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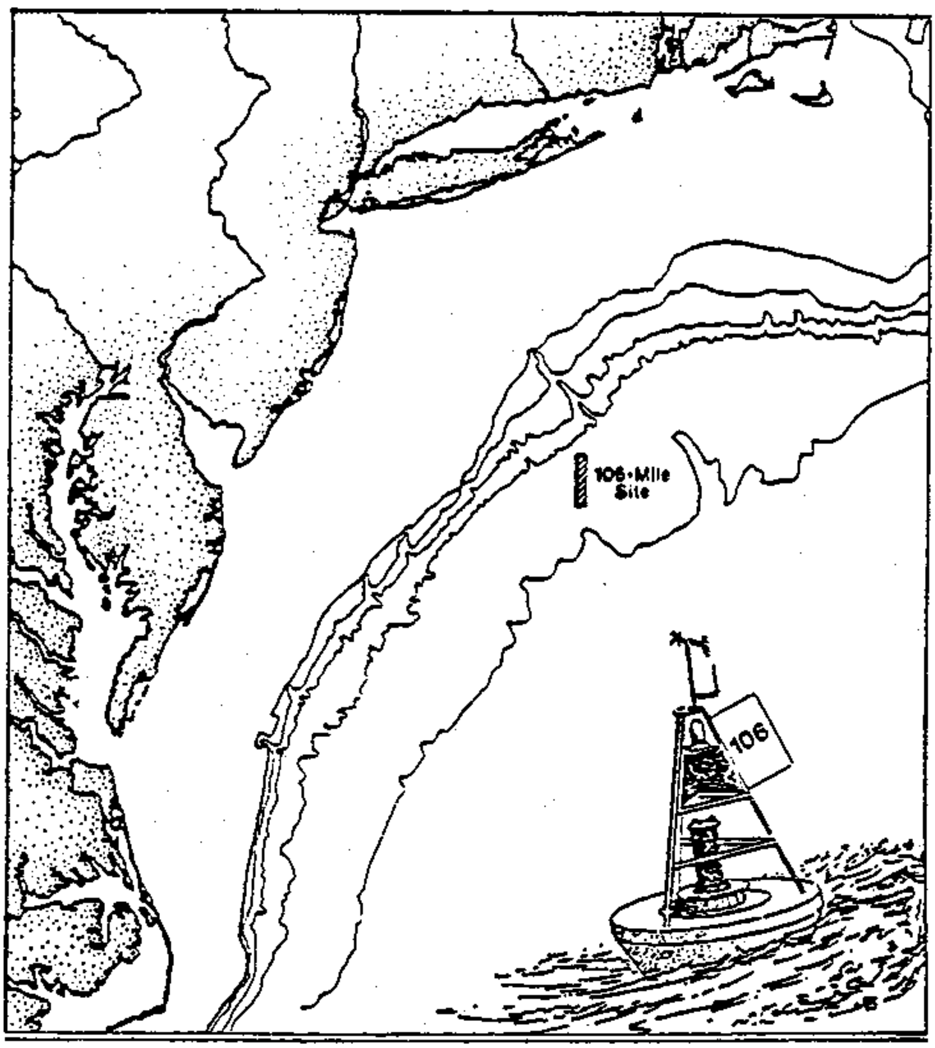
Final Report for 106-Mile Deepwater Dumpsite Winter 1988 Survey



FINAL REPORT

106-MILE DEEPWATER DUMPSITE
WINTER 1988 SURVEY

November 3, 1988

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Marine and Estuarine Protection
Washington, DC

and

Region II
New York, New York

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA), under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA, PL 92-532), is monitoring the 106-Mile Deepwater Municipal Sludge Site (106-Mile Site). The objective of the 106-Mile Site monitoring program is to ensure that provisions of EPA's ocean dumping regulations are met through assessment of compliance with permit conditions and assessment of potential impacts on the marine environment. The program is being implemented according to a tiered approach, whereby data collected in each tier are not only used in making site management decisions but also are required as the foundation for the design and extent of monitoring activities in the next (lower) tier. Four tiers are included in the monitoring program: (1) Sludge Characteristics and Disposal Operations; (2) Nearfield Fate and Short-Term Effects; (3) Farfield Fate; and (4) Long-Term Effects.

This report presents the results from nearfield fate studies conducted at the site in March 1988. Currently, dumping at the site is conducted under court order. If permits for disposal of sludges are issued, they will stipulate that water quality criteria (WQC) and limiting permissible concentrations (LPC) may not be exceeded within the site four hours after dumping or outside the site at any time. Nearfield fate determinations address the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Monitoring behavior and movement of sludge immediately after disposal is necessary to confirm assumptions regarding dispersion and dilution that were made in issuing permits. Nearfield fate monitoring also addresses the potential for impacts within the immediate vicinity of the site and in the short-term. This information will also be used to guide monitoring activities to assess short-term biological effects of sludge disposal.

The 106-Mile Site monitoring plan presents several hypotheses related to nearfield fate of sludge plumes, and these hypotheses were tested during the survey. Results from the survey indicated the following:

Permit Compliance

H_o3: Concentrations of sludge and sludge constituents outside the site are below the permitted LPC and WQC at all times.

> Because of low surface current drift at the site during the time of the survey, sludge plumes monitored at the site were not observed to cross site boundaries during the March 1988 survey. Analysis of transport suggests that water quality criteria would not be exceeded outside the site for these plumes.
>
> One barge was found dumping outside of site boundaries. Concentrations of sludge and sludge constituents probably exceeded permitted levels for this plume.

H_o4: Concentrations of sludge and sludge constituents within the site are below the permitted LPC and WQC 4 h after disposal.

Concentrations of all sludge contaminants for which there are marine WQC were below or calculated to be below WQC 4 h after disposal, as determined by analysis of water samples in sludge plumes. Dilution rates of plume cores (most concentrated parcels) calculated from transmissometry suggest that had samples been collected in the plume core of DB-13, WQC would have been exceeded for at least copper and lead. Therefore, at least for this plume, samples collected for water quality analyses probably were not representative of the most concentrated volume in the plume and therefore WQC data for this survey may have underestimated contaminant levels at the site.

H_o5: Pathogen levels do not exceed ambient levels 4 h after disposal.

The microbial tracer, C. perfringens, exceeded ambient levels in the only sludge plume sampled at T=4 h. C. perfringens is not a pathogen, but a conservative microbial tracer of sewage; therefore, C. perfringens data are not conclusive proof that pathogen levels are being exceeded 4 h after disposal. Measurements of C. perfringens suggested that this hypothesis was false, direct measurements of pathogens will be required to prove it false.

Impact Assessment: Nearfield Fate

H_o6: Sludge particles do not settle in significant quantities beneath the seasonal pycnocline (50 m) or to the 50-m depth at any time, within the site boundaries or in an area adjacent to the site.

Sludge was observed to penetrate the surface pycnocline (between shelf and slope waters) and descend to 80 m within 3 h after dumping during one dumping event. The deep penetration may have been related to a dumping rate in excess of the court-ordered 15,500 gal/min. Sludge dumped at the court-ordered rate of 15,500 gal/min or less was observed to remain within the upper 25 m during winter oceanographic conditions. This hypothesis was therefore demonstrated to be false under the observed conditions.

H_07: The concentration of sludge constituents within the site does not exceed the LPC or WQC 4 h after disposal and is not detectable in the site 1 day after disposal.

As stated in H_04, sampling and analysis of water samples for sludge constituents was insufficient to determine if WQC were exceeded 4 h after disposal.

Some surface water collected for background contaminant analysis contained metal contaminant levels approaching or exceeding WQC. The high levels probably resulted from previous dumping activity at the site, although this cannot be verified from the data. In the absence of surface currents that would remove surface contamination, the frequency of dumping creates the potential for contaminants to accumulate in surface waters.

Although not observed, the rapid formation of two fractions of sludge plumes (one containing dissolved contaminants, the other containing particulate matter) can be predicted from the limited data set on dissolved and particulate contaminants in sludge plumes. A plume of dissolved contaminants would not disperse rapidly under conditions observed at the site, and the predicted presence of such a plume might be the cause of the elevated contaminant levels in background samples.

H_08: The concentration of sludge constituents at the site boundary or in the area adjacent to the site does not exceed the LPC or WQC at any time and is not detectable 1 day after disposal.

No plumes dumped in the site were observed to cross site boundaries within 4 h during the March 1988 survey.

It was estimated that one sludge plume monitored outside the site could have easily been monitored for over 24 h given the high TSS levels and rate of dilution. The high TSS levels were believed due to a dumping rate in excess of the court-ordered maximum. This hypothesis was probably false under the conditions observed during the survey.

H_o9: The disposal of sludge does not cause a significant depletion in the dissolved oxygen content of the water nor a significant change in the pH of the seawater in the area.

> The observed depression in dissolved oxygen levels in sludge plumes is minor and at the limit of instrument resolution. During the winter survey, pH was not monitored in sludge plumes.

Because of limitations associated with water quality measurements at the site, the assessment of sludge plume behavior and transport under winter conditions is considered incomplete. Sludge dispersion and transport data indicate that under quiescent oceanographic conditions the settling and dispersion of sludge in winter is similar to that observed during summer. The preliminary results of this survey were used to plan appropriate measurements of short-term effects of sludge dumping, and helped guide plans for assessing farfield fate of sludge constituents.

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1.0 INTRODUCTION

Under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA, PL 92-532), the U.S. Environmental Protection Agency (EPA) is responsible for regulating disposal of wastes, including sewage sludges, in ocean waters. Under this authority, EPA has published ocean dumping regulations (40 CFR Parts 220-229) that specify procedures for monitoring ocean dumpsites. EPA's responsibility for developing and maintaining monitoring programs for designated ocean disposal sites is described in these regulations.

In carrying out the responsibility for developing monitoring programs, EPA has prepared a monitoring plan for the 106-Mile Deepwater Municipal Sludge Site (106-Mile Site) (EPA , 1992a). The site is located off the coast from New York and New Jersey (Figure 1-1). Data generated by the program will be used by site managers to make decisions about site redesignation or dedesignation; continuation, termination, or modification of permits; and continuation, termination, or modification of the monitoring program itself.

The objective of the 106-Mile Site monitoring program is to ensure that the regulations are met through assessment of compliance with permit conditions and assessment of potential impacts on the marine environment. The program is being implemented according to a tiered approach, whereby data collected in each tier are not only used in making site management decisions but are also required as the foundation for the design and extent of monitoring activities in the next (lower) tier. Four tiers are included in the monitoring program: (1) Sludge Characteristics and Disposal Operations; (2) Nearfield Fate and Short-Term Effects; (3) Farfield Fate; and (4) Long-Term Effects.

Nearfield fate studies being conducted under Tier 2 of the monitoring program address both the permit compliance and the impact assessment components of monitoring at the site. Currently, dumping at the site is conducted under court order. When permits for disposal of sludges are issued, they will stipulate that water quality criteria (WQC), where they exist, may not be exceeded within the site 4 h after dumping or outside the site at any time. When WQC do not exist, the permits will require that the

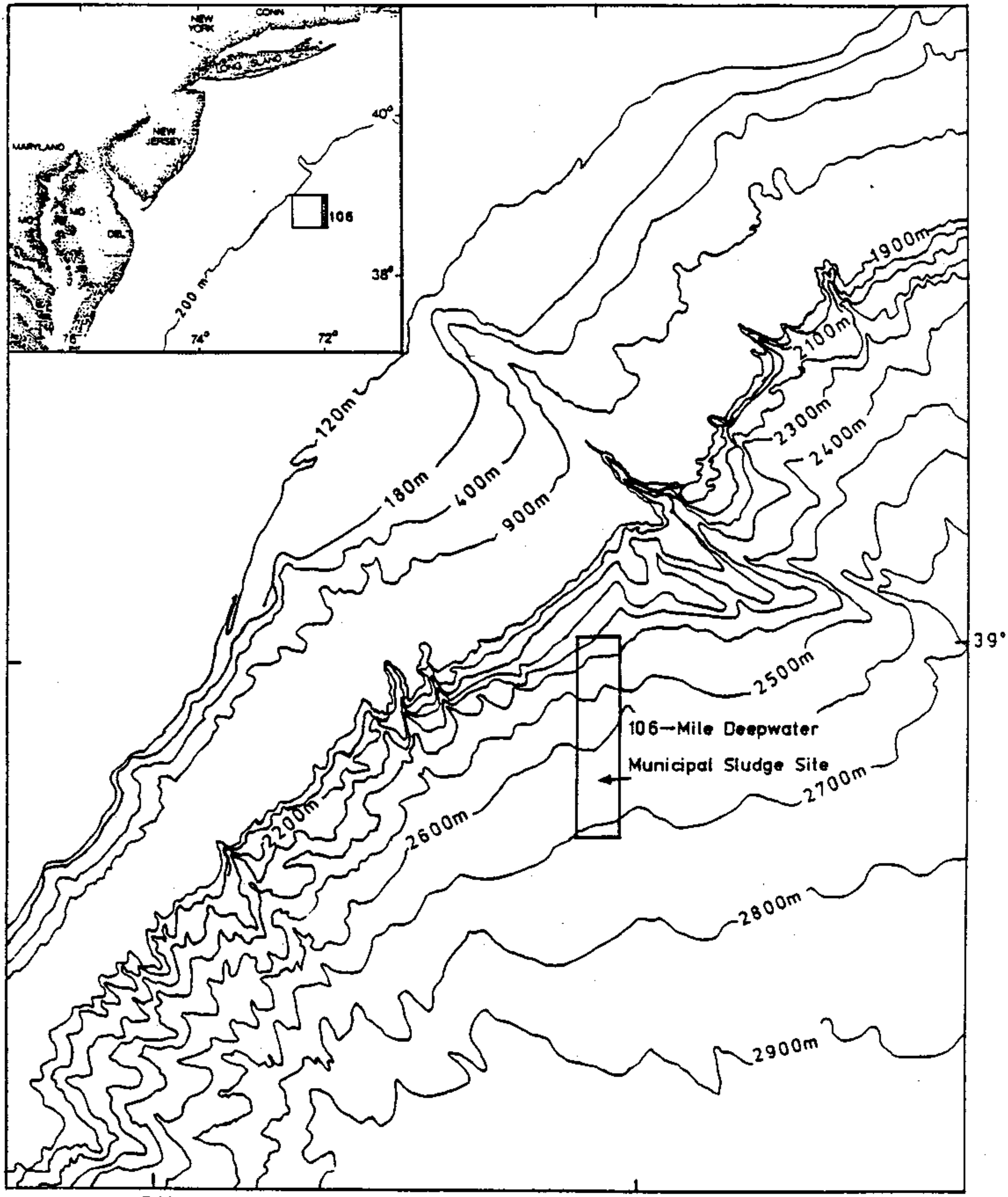


FIGURE 1-1. LOCATION OF THE 106-MILE DEEPWATER MUNICIPAL SLUDGE SITE.

concentration of the sludge not exceed a factor of 0.01 times a concentration known to be acutely toxic after initial mixing, i.e., the limiting permissible concentration (LPC). The combined conformance to LPCs and WQC is thought to be protective of the marine environment.

Nearfield fate monitoring also addresses the potential for impacts within the immediate vicinity of the site and in the short term, defined for convenience as 24 h. Nearfield fate determinations address the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Monitoring behavior and movement of sludge immediately after disposal is necessary to confirm assumptions regarding dispersion and dilution that will be used in issuing permits. This information will also be used to guide monitoring activities to assess short-term biological effects of sludge disposal.

The 106-Mile Site monitoring plan presents the following hypotheses related to nearfield fate of sludge plumes:

Permit Compliance

H_o3: Concentrations of sludge and sludge constituents outside the site are below the permitted LPC and WQC at all times.

H_o4: Concentrations of sludge and sludge constituents within the site are below the permitted LPC and WQC values 4 h after disposal.

H_o5: Pathogen levels do not exceed ambient levels 4 h after disposal.

Impact Assessment

H_o6: Sludge particles do not settle in significant quantities beneath the seasonal pycnocline (50 m) or to the 50-m depth at any time, within the site boundaries or in an area adjacent to the site.

H_o7: The concentration of sludge constituents within the site does not exceed the LPC or WQC 4 h after disposal and is not detectable in the site 1 day after disposal.

H_o8: The concentration of sludge constituents at the site boundary or in the area adjacent to the site does not exceed the LPC or WQC at any time and is not detectable 1 day after disposal.

H_o9: The disposal of sludge does not cause a significant depletion in the dissolved oxygen content of the water nor a significant change in the pH of the seawater in the area.

The activities being conducted under Tier 2 have been selected to test these hypotheses. These activities include direct studies of sludge plumes under varied oceanographic and meteorological conditions. Specifically, Tier 2 includes the following activities designed to assess nearfield fate, as described in an implementation plan that supplements the monitoring plan for the site (EPA , 1992b):

Permit Compliance

Measure sludge constituents in the water column to determine fate of sludge constituents, with respect to permit conditions and ambient conditions. Measurements of water quality, and chemical and microbiological parameters are being made to determine whether concentrations of sludge constituents meet permit conditions and are at background levels within 1 day after disposal. These measurements address null hypotheses 3 through 5 and 7 through 9.

Impact Assessment

Conduct sludge plume observations to define the seasonal patterns of sludge dispersion at the 106-Mile Site. Nearfield fate studies include use of a variety of methods to track sludge plumes under summer and winter conditions. These studies are being used to determine when and where samples should be taken, when and where the sludge plume crosses the site boundary, and where to sample to determine whether sludge constituents are detectable 1 day after disposal. They also provide information on whether sludge particles settle beneath the pycnocline. The studies provide information to guide sampling for sludge constituents in the water column and also address H_o6.

Preliminary observations of plume transport at the site were made during an EPA survey of the site in September 1986 (EPA , 1988a). Visual observations and measurements of sludge tracers (total suspended solids and spores of the microbe Clostridium perfringens) indicated that sludge plumes could be tracked to the boundaries of the 106-Mile Site. These preliminary observations indicated that there is a potential for violating permit conditions and for adverse short-term impacts from disposing sludge at the site.

EPA then developed a strategy for comprehensive assessment of nearfield, short-term fate of sludge constituents (EPA , 1987a). This strategy outlined a plan for assessing various methods of tracking sludge plumes and for measuring compliance with expected permit conditions. It presented the following specific information to be obtained during nearfield fate monitoring at the site:

Permit Compliance

- Determination of whether sludge constituents for which there are WQC are present in concentrations above the WQC within the site boundaries within 4 h after dumping and outside the site boundaries at any time.

- Determination of whether concentrations of the microbe Clostridium perfringens exceed ambient levels within the site 4 h after disposal.

Impact Assessment

- Determination of the dilution of sludge in seawater immediately upon dumping and during the first hour after dumping.

- Determination of the short-term effects of sludge on the dissolved oxygen levels at the site.

- Determination of the rate and direction of movement of the surface and subsurface expression of the plume within the site.

- Determination of the extent of horizontal dispersion of the plume.

- Determination of the extent of vertical dispersion of the dissolved and particulate components of the plume.

- Determination of the effect of a seasonal pycnocline on the settling of sludge.

Surveys addressing these issues were conducted at the 106-Mile Site in September 1987 and again in March 1988. Results of the September 1987 survey have been described previously (EPA , 1992c). Results of the March 1988 survey are presented in this report. Chapter 2 presents the strategy for making nearfield fate measurements of sludge constituents and tracers of sludge plumes. Chapter 3 describes the sample collection and analysis methods. Chapter 4 describes the oceanographic conditions in the region of the site at the time of the survey and presents the results of the analyses. The conclusions of the study, including an assessment of behavior and transport of plumes in terms of the null hypotheses and a comparison to the September 1987 survey, are presented in Chapter 5.

The survey was conducted from March 1 to March 5, 1988 on board the Reasearch/Vessel (R/V) Endeavor operated by the University of Rhode Island. The survey was mobilized and demobilized out of Narragansett, Rhode Island. The survey monitored six plumes, identified as DB-10 through DB-15, on March 2 through 4, 1988 (Table 1-1). A complete description of the survey is presented in the initial survey report and in the site condition report for the survey (EPA , 1988b and 1988c).

Key personnel involved in this work assignment included Frank Csulak, EPA Co-Work Assignment Manager and Chief Scientist for the survey; Barry Burgan, EPA Co-Work Assignment Manger; Christine Werme, Technical Monitor; William Steinhauer, Work Assignment Leader; Scott McDowell, Chief Battelle Scientist for the survey; and Carlton Hunt, Task Manager for all laboratory activities.

Survey participants are listed in Table 1-2. Individuals involved in laboratory activities and data analysis are presented in Table 1-3. William Steinhauer, Scott McDowell, Carlton Hunt, and Christine Werme authored this report.

TABLE 1-1. BARGES THAT DUMPED MUNICIPAL SEWAGE SLUDGE AT THE 106-MILE SITE DURING THE SURVEY OPERATIONS FROM MARCH 2 THROUGH MARCH 4, 1988.

Plume Survey	Tug	Barge	Dumping Time (h)	
DB-10	Sheila Moran	Lemon Creek	1212 1614	3/2 to 3/2
DB-11	Emily-S	Leo Frank	2011 2303	3/2 to 3/2
DB-12	Elizabeth	Weeks 701	0712 0950	3/3 to 3/3
DB-13	Kate	Morris Berman	2006 2223	3/3 to 3/3
DB-14	Esther Moran	Spring Creek	0719 0922	3/4 to 3/4
DB-15	--	OBI4	1102 1133	3/4 to 3/4

TABLE 1-2. LIST OF PARTICIPANTS, WINTER 1988 OCEANOGRAPHIC SURVEY

EPA REGION II	
Frank Csulak	Chief Scientist
Joseph Hudek	Dye Studies
BATTELLE	
Scott McDowell	Task Leader, XCPs, Aerial Reconnaissance
Carlton Hunt	Vertical Profiling and Sampling
Wayne Trulli	Sampling and Sample Tracking
Carl Albro	CTD, Computer Support
Jeffery Waugh	Sampling
Deborah West	Sampling
Felicia Giordano	Microbiology
Charles Willauer	Navigation
MANOMET BIRD OBSERVATORY	
Burt Nickerson	Endangered Species Observations
NEW YORK DEPARTMENT OF ENVIRONMENTAL PROTECTION	
Thomas Brosnan	Sampling
UNIVERSITY OF RHODE ISLAND, GRADUATE SCHOOL OF OCEANOGRAPHY	
Viva Banzon	Sampling, Microbiology

TABLE 1-3. PARTICIPATING PERSONNEL, LABORATORY ACTIVITIES, AND DATA ANALYSIS.

Chemical Analysis	
Carlton Hunt	Task Manager, Chemical Analyses and Interpretation
Dion Lewis	Subtask Leader, Inorganic Analyses
Carole Peven	Subtask Leader, Organic Analyses
Debbie West	Inorganic Analyses
Larisa Altshul	Organic Analyses
George Desreuisseau	Organic Analyses
Bernadette Koczwara	Organic Analyses
Physical Oceanographic Data Analyses	
Scott McDowell	Task Manager, Physical Oceanographic Data Analyses
Carl Albro	Data Analysis
Charles Willauer	Data Analysis

2.0 SURVEY OBJECTIVES AND STRATEGY

The objectives of the survey of the 106-Mile Site were to employ a variety of methods to (1) assess the movement, dilution, and settling of sewage sludge as sludge plumes are transported towards and beyond the site boundary, and (2) determine whether water quality requirements that will be included in permits for dumping at the site are being met during ongoing disposal operations. The survey was the second field application of proposed technical methods for nearfield fate monitoring at the 106-Mile Site, and the first to be conducted under winter conditions. Therefore, an additional objective was to test equipment and protocols for future nearfield fate monitoring activities that may be conducted by EPA or by permittees.

EPA strategy to accomplish these objectives involved conducting the following activities in the survey:

- Identification and tracking of a sludge plume with dye and surface and subsurface drogues.
- Monitoring of the movement and dispersion of the marked sludge plume with visual observations from the R/V Endeavor and an aircraft.
- Acquisition of in situ transmissometry data to monitor the movement and dispersion of the plume.
- Collection of samples for analysis of chemical and biological tracers and total suspended solids (TSS) to determine actual concentrations of sludge components and dilution of these components.
- Collection of samples for analysis of those contaminants that have marine water quality criteria (Table 2-1) to determine water quality in the plume 4 h after disposal, or at the site boundary if the sludge leaves the site before 4 h.
- Acquisition of data to determine oceanographic conditions at the site that may affect the movement of sludge. These data included satellite-derived ocean frontal analyses; conductivity/temperature/depth (CTD) profiles; and current shear measurements.
- Acquisition of real-time navigation data to support plume-tracking activities.

TABLE 2-1. ELEMENTS AND COMPOUNDS FOR WHICH THERE ARE MARINE WATER QUALITY CRITERIA.[a]

Inorganic Elements	Arsenic Cadmium Chromium (hexavalent) Copper Cyanide Lead Mercury Nickel Selenium Silver Zinc
Organic Compounds	Aldrin/Dieldrin Chlordane DDT and Metabolites Endosulfan Endrin Heptachlor PCBs Toxaphene

[a]All samples on this work assignment were analyzed for total chromium instead of hexavalent chromium. Cyanide was not analyzed.

- Observations of endangered species of cetaceans, marine turtles, and seabirds, according to EPA policy to evaluate these animals on all surveys of the 106-Mile Site.

These activities were grouped into major survey activities. A summary of the major nearfield fate monitoring activities is presented in Table 2-2.

TABLE 2-2. MONITORING ACTIVITIES.

Activity	Subactivity
Transect CTD Profiles	None
Shakedown Exercises	Testing of all oceanographic gear. Activities include vertical profiling with CTD/transmissometer and collection of water samples for WQC contaminants.
Vertical Profiling	CTD/transmissometer vertical profiling; collection of discrete water samples for tracers, metal WQC samples, TSS, and *C. perfringens*; collection of water for organic WQC samples with pumping system (surface) and Bodman bottles (50 m); XCP profiling.
Horizontal Profiling	Towed fish with CTD/transmissometer, transmissometer; XCP profiling.

3.0 SAMPLE COLLECTION AND ANALYSIS METHODS

The primary method for the nearfield monitoring of sludge plumes was use of transmissometry, which measured turbidity resulting from high levels of total suspended solids in sludge. Real-time acquisition of conductivity, temperature, depth, transmissometry, and dissolved oxygen data resulted in large amounts data from horizontal profiles. The same in situ data were acquired during vertical profiles which were augmented by the collection of water samples for chemical and microbiological tracers and marine water quality parameters. However, unlike the previous survey in which chemical tracer and microbiological samples were collected with a pumping system, the samples on the winter survey were collected using individual sampling bottles. Surveying operations were also supported with aerial photoreconnaissance. The aerial photoreconnaissance provided information on lateral plume spreading and plume orientation.

The most obvious improvement in this survey over the previous nearfield fate monitoring survey was the use of the real-time navigation system developed for the survey. Acquisition and display of real-time navigation data provided data critical for maneuvering the vessel during nearfield fate profiling and provided excellent support for the other measurements made during the survey. The necessity of this navigation support on all future monitoring surveys at the 106-Mile Site was demonstrated.

3.1 PHYSICAL OCEANOGRAPHIC MEASUREMENTS

Physical oceanographic data were acquired during the survey by obtaining vertical and horizontal profiles of water column parameters, obtaining vertical profiles of surface currents, and deploying near-surface drifters.

3.1.1 Water Column Profiling

Vertical and horizontal water column profiling was performed with a Sea-Bird Electronics conductivity-temperature-depth (CTD) system interfaced to an IBM-PS/2 personal computer. A Sea-Bird Electronics dissolved oxygen sensor and a Sea Tech 25-cm pathlength transmissometer were also interfaced to the CTD underwater unit for concurrent, in situ measurements of oxygen and turbidity (derived from percent light transmission). The CTD underwater unit and sensor package was attached to the lower side of a 3-foot (wingspan) Endeco V-Fin depressor.

The CTD underwater unit transmitted digital information to a deck control unit via a Kevlar electromechanical (E/M) profiling cable. The CTD deck control unit passed the raw CTD data to the computer of the shipboard data acquisition system for real-time display and data storage. A Northstar Model 7000 Loran-C receiver was also interfaced to the computer system to obtain and record vessel position information (Loran-C time delays, latitude, and longitude) at 6-second intervals during surveying operations. Figure 3-1 illustrates the hardware configuration of the hydrographic data system developed by Battelle for the operations. Measurement specifications for each of the sensors are presented in Table 3-1.

Following the survey, binary data files of the digital CTD data were returned to the laboratory for processing and review. The package for processing CTD data from vertical profiles and horizontal tows was used to perform the following functions:

- Conversion of raw (binary) CTD data into engineering units: depth (m), temperature (°C), salinity (ppt), oxygen (mL/L), and light transmission (percent light extinction).
- Removal of data points that lie outside reasonable, site-specific ranges for each measurement parameter.
- Retention of data points only when the depth series is monotonically increasing (because good quality CTD data can only be obtained when the sensors are descending through the water column and passing through undisturbed water).

For CTD data files acquired during horizontal profiling operations, the processing procedures were identical to those described above, except that data were not excluded on the basis of depth changes because the sensors are continually towed through undisturbed water.

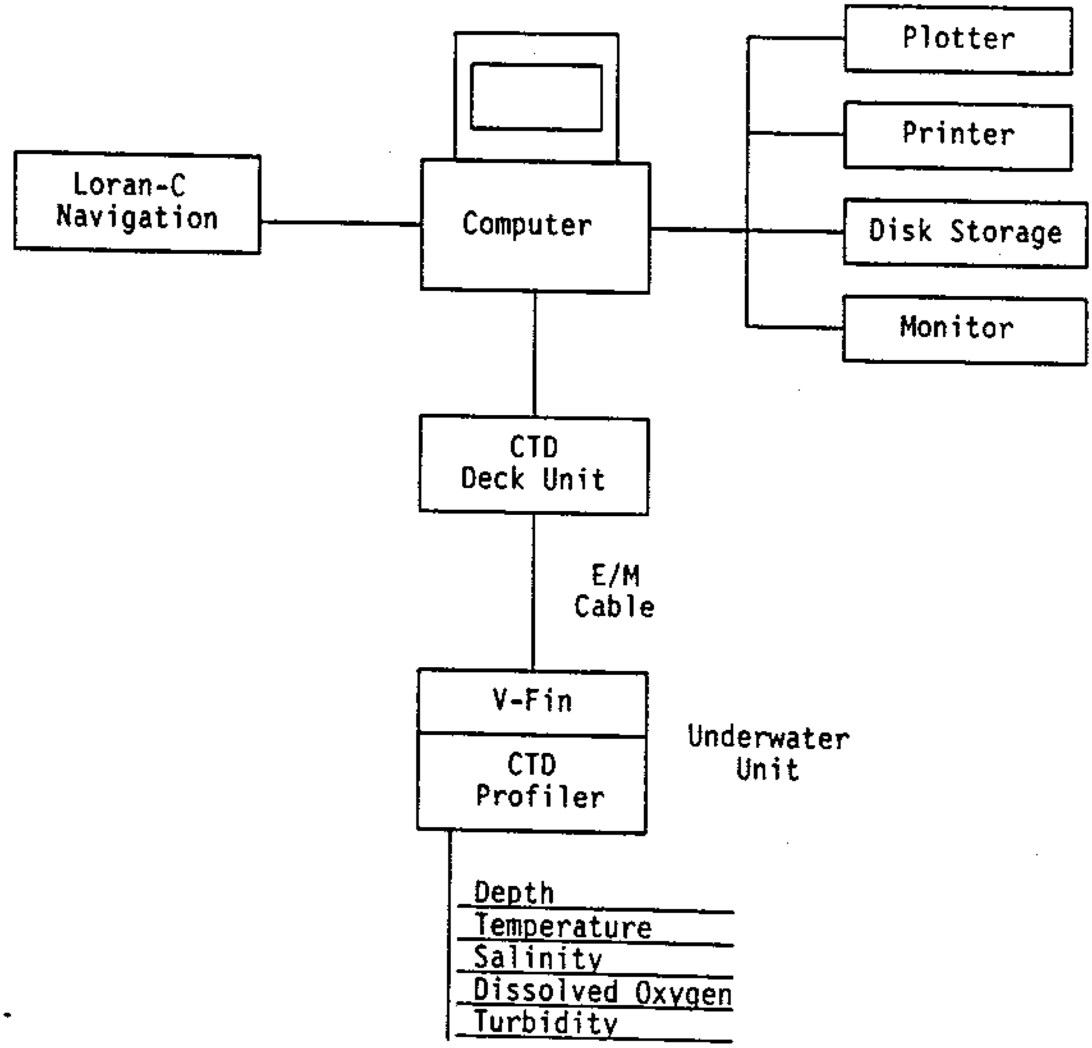


FIGURE 3-1. SCHEMATIC DIAGRAM OF SHIPBOARD DATA ACQUISITION SYSTEM

TABLE 3-1. MEASUREMENT SPECIFICATIONS FOR CTD SENSORS.

Parameter	Range	Accuracy	Resolution
Depth	0 to 3000 m	±60 cm	12 cm
Temperature	-5 to 35°C	±0.004°C	0.0003°C
Salinity	0 to 40 ppt	±0.005 ppt	0.0005 ppt
Oxygen	0 to 15 mL/L	±0.1 mL/L	0.01 mL/L
Light Transmission	0 to 100 %	±0.5 %	0.01 %

Sampling rate: 24 samples per second (averaged to 8 samples per second).

Vertical resolution during profiling: ~4 cm for 20 m/min lowering speed.

Horizontal resolution during towing: ~20 cm at 3-knot ship speed.

Additional information regarding the configuration of the CTD, and acquisition and reduction of these data is found in EPA (1992c).

3.1.2 Current Measurements

Vertical profiles of horizontal currents in the upper 1500 m of the water column were acquired using an expendable current profiling (XCP) data acquisition system and XCP probes manufactured by Sippican Ocean Systems. The XCP data acquisition system consisted of a Hewlett-Packard Model 9816 microcomputer, an XCP controller unit containing a radio receiver, and a radio antenna mounted on the upper deck of the survey vessel. For profiling operations, an XCP probe was launched behind the vessel and data were transmitted via the radio link to the on-board XCP data acquisition system. During each profile, which lasted roughly 6 minutes, engineering information was stored in computer memory for near real-time analysis. After the profile cycle was complete, a processing program was used to convert the raw data into engineering units of current speed, current direction, and water temperature versus depth. These results were plotted within one half hour after the launch to provide information on current shear in the upper water column that would affect plume advection and tracking operations. XCP data were stored on floppy disks for easy access from analysis programs.

Near-surface drifters, designed to maximize the cross-sectional area of the drogue while minimizing the surface area and windage of the surface markers, were fabricated specifically to track sludge plumes. For each nearfield fate event except DB-12, one "shallow" drifter was deployed with a drogue tethered 5 m below the surface. These drifters remained with both the surface expression of the sludge plumes and the dye released within the plumes for periods of several hours. A "deep" drifter, having a drogue tethered at a depth of 50 m, was deployed alongside a shallow drifter during plume events DB-10 and DB-14 to observe the currents beneath the seasonal pycnocline. Except for DB-12, the sludge plumes were apparently confined to the upper 20 m of the water column in the short-term, and there was no operational need for tracking water beneath the pycnocline.

Drifters were tracked visually from the survey vessel. During vertical profiling operations, the vessel would periodically stop alongside the drifter to obtain a Loran-C position. During horizontal profiling, drifter positions were obtained when the vessel passed the drifter during repeated transects of the plume. All Loran-C drifter positions and times were recorded by the computer system used to acquire the hydrographic data. For each drifter, a file of positions and times was archived to facilitate analyses of trajectories and current vectors.

3.2 WATER SAMPLE COLLECTION

3.2.1 Water Samples for Tracers and Metal Water Quality Parameters

Collection methods for water samples for metals analysis were different than those employed during the summer survey (EPA , 1992c). The sampling strategy was modified because under winter oceanographic conditions the sludge was expected to descend to depths beyond the ability of existing pumping systems. Additionally, rough winter seas were expected to interfere with the use of the existing deck-mounted pumping system.

Go-Flo bottles directed by real-time CTD/transmissometry data were used to collect metals and tracer water samples because this system had a high probability of successfully returning samples from plumes that descend deep into the water column. Two systems were developed to enable collection of samples from the water column between 0 and 5 m, and between 0 and 100 m. For collection of surface samples between 0 and 5 m, two Go-Flo bottles were attached to a frame containing a small CTD and 25-cm-pathlength transmissometer. For collection of samples from below 5 m, Go-Flo bottles were attached to the electromechanical cable used to deploy the V-fin housing the Seabird CTD/transmissometer system. For both systems, the Go-Flo bottles were closed using messengers.

The sampling strategy was to collect all metals and tracer water samples in the particle maximum as determined from the real-time display of in situ parameters from the CTD profiling system. However, difficulties in deploying, triggering, and retrieving bottles, and the rapid movement of the ship' relative to the sludge plume limited the practicality of the strategy for sampling sludge plumes. Also, correlating sample collection to transmissometry observations proved more difficult than anticipated because time of bottle closure could not be electronically verified on deck.

Samples from the Go-Flo bottles were processed for laboratory trace metal and total suspended solids (TSS) analysis, and for shipboard C. perfringens enumeration. Samples for TSS were used for analysis of particulate metal concentrations in the plume.

3.2.2 Water Samples for Organic Contaminants

Large-volume organic samples were collected using two techniques. For samples from depths greater than 5 m, 100-L aluminum sampling bottles (Bodman bottles) were used. Samples from the ocean surface were collected using a high-volume pumping system. Water collected by both methods was transferred immediately to deck-mounted 100-L extraction containers. Extractions were performed on board within 4 h of sample collection (EPA , 1992c).

3.2.3 Processing of Tracer Samples and C. perfringens

Samples for analysis of sludge tracers and water quality parameters were processed by removing samples from the Go-Flo bottles under nitrogen pressure. Samples for analysis of C. perfringens were collected before those for analysis of metal tracers. If a sample for mercury analysis was required, it was collected after the metal tracer sample. All water quality and metal tracer samples were acidified on board the survey vessel. Samples for C. perfringens were processed on board as outlined in EPA (1992c).

3.2.4 Processing of Particulate Matter

Samples for analysis of total suspended solids (TSS) and particulate trace metals were collected from the Go-Flo bottles after whole-water tracer samples were collected. The samples were filtered directly from the Go-Flo bottles using nitrogen pressure filtration. Seawater was forced at a constant pressure of 5 psi through a Teflon tube attached to an in-line filter holder containing a 47-mm 0.4-μm Nuclepore filter. The amount of seawater passing the filter was determined volumetrically. Filtering was stopped when seawater no longer passed the filter. All filters were then rinsed with three 10 mL rinses of deionized water adjusted to pH 8 with NH_4OH. All processing was conducted at a Class-100 clean bench.

3.3 ENDANGERED SPECIES OBSERVATIONS

Because of concern for the possible impact of ocean dumping activities on endangered or threatened species of marine mammals and turtles, the presence of these species in the area was recorded. Observations were made by a qualified observer on the R/V Endeavor. These observations were recorded along predetermined survey paths in 15-min periods, where each period represented a transect.

The data were recorded in two major categories--location/environmental and species/behavior. Information in each category was recorded for each 15-min observation period and both categories were identified by a unique survey and observation number. Location/environmental data included latitude-longitude, start time, elapsed time, vessel speed and course, water depth and temperature, barometric pressure trend, visibility, and wind direction and speed. Species/behavior data included taxonomic group, species identification, number of animals observed, age, distance and angle to sightings, heading, animal association, debris association, and behavior.

3.4 ANALYTICAL METHODS

Summaries of the data requirements for shipboard and laboratory analytical methods are presented in Table 3-2. Quality control methods used to verify the accuracy and precision of these methods are presented in the work/quality assurance project plan for this work assignment (EPA , 1992d). Results of the laboratory analytical quality control program are discussed in Appendix A and presented in Tables A-1 through A-8 in Appendix A. Analytical methods are presented below.

TABLE 3-2. OBJECTIVES FOR ANALYTICAL MEASUREMENTS OF WHOLE WATER AND PARTICULATE SAMPLES.

Parameter.	Laboratory Analyses[a]					
	Units	Detection Limit	Accuracy	Precision	Method	SOP[b]
Filtrate or Particulates						
WQC Organics	μg/L	.0001-.005	50	100	Solvent Extraction, GC/ECD	6-08
Metals						
Filtrate						
Ag	μg/L	.015	50	30	Chelation-extraction pH 1.8, GFAA	New Method
Cr	μg/L	.030	50	30	Chelation-precipitation, GFAA	6-04
Cd, Cu, Fe, Pb, Zn	μg/L	.015-.030	50	30	Chelation-extraction, GFAA	6-05
As, Se	μg/L	.050	50	30	Hydride generation AA	New Method
Total Hg	μg/L	.0015	50	30	Cold vapor AA	6-03
Particulate						
Metals	mg/L	.01-.5	50	30	Acid digestion, GFAA	New Method
TSS	mg/L	.01	30	30	Filtration, gravimetric	New Method

[a]Precision and accuracy of laboratory results addressed as percent of true values.

[b]Refers to EPA-approved SOPs for analytical procedures in support of the 106-Mile Site monitoring program (Battelle 1987b).

3.4.1 Trace Metals

Methods for the extraction and analysis of trace metals are summarized below.

3.4.1.1 Cadmium, Copper, Iron, Lead, Nickel, and Zinc

Unfiltered seawater samples were extracted at pH 5 with a 1 percent solution of purified ammonium-1-pyrrolidine dithiocarbamate diethylammonium diethyldithiocarbamate (APDC-DDDC) and Freon (Danielsson et al., 1982). Each sample was extracted three times with 5-mL aliquots of Freon; all Freon extracts were combined. The metals were back-extracted into 2 mL of 10 percent nitric acid. The nitric acid solutions were analyzed for cadmium, copper, iron, lead, nickel, and zinc by graphite furnace atomic absorption spectrometry (GFAAS) with Zeeman background correction.

3.4.1.2 Silver

Unfiltered seawater samples were extracted at pH 1.8 using the APDC-DDDC procedure outlined above. Silver was analyzed using GFAAS.

3.4.1.3 Chromium

Total chromium was determined using a modification of the methods described by Cranston and Murray (1977). Chromium was coprecipitated with 0.01 N $Fe(OH)_2$ after an aliquot of seawater was adjusted to pH 8 with NH_4OH. The resulting precipitate was filtered and digested with 6 N nitric acid. After dilution with deionized water to a known volume, the acid digests were analyzed for total chromium by GFAAS.

3.4.1.4 Mercury

Mercury in seawater was determined according to the method of Gill and Fitzgerald (1987). Mercury in a known volume of seawater was reduced with stannous chloride in a closed vessel. The sample was purged with nitrogen and the resulting elemental mercury was concentrated on gold-coated quartz sand. Using heat, the amalgamated mercury was quantitatively desorbed from the gold trap into a stream of helium and analyzed with a Laboratory Data Control UV mercury monitor.

3.4.1.5 Selenium and Arsenic

Selenium and arsenic were determined by hydride generation of aliquots of unfiltered seawater. Selenium and arsenic were reduced with a 3 percent solution of sodium borohydride. The elements were subsequently purged from the sample into a heated quartz cell and quantified by AAS.

3.4.2 Organic Compounds

High-volume seawater samples (100 L) were extracted with 4 L dichloromethane (DCM) in 150-L stainless steel extraction vessels on board ship. The solvent layer was removed and the aqueous sample was reextracted twice with 2-L aliquots of DCM. Extracts were shipped to the laboratory for analysis. In the laboratory, the extracts from each sample were combined and reduced in volume. Concentrated extracts were fractionated on silica-alumina columns to remove matrix interferences.

Pesticides and polychlorinated biphenyls (PCBs) were analyzed by electron capture detection capillary column gas chromatography (GC-ECD) (EPA , 1987b). Response factors for each compound were determined relative to the internal standard dibromooctafluorobiphenyl. Field and laboratory recoveries were determined through the use of surrogate materials. All analytes reported were confirmed using the second column approach.

3.4.3 Total Suspended Solids (TSS)

In the laboratory, samples were air dried in a Class-100 clean room and the mass of the loaded filter determined. The concentration of TSS was calculated based on the weight of solids collected on the filter divided by the volume of seawater filtered (EPA , 1987c).

3.4.4 Clostridium perfringens

Enumeration of *C. perfringens* in seawater was performed according to the methods of Bisson and Cabelli (1979). *C. perfringens* spores were collected by filtering 0.1-, 0.5-, and 1-L aliquots of seawater through 0.4-μm polycarbonate filters immediately after collection. The filters were cultured anaerobically on modified *C. perfringens* (m-CP) medium. Confirmation was obtained by exposing the incubated plates to ammonium hydroxide vapors, which turn *C. perfringens* colonies a magenta color. The bacteria were quantified as number of colonies per 100 mL of filtered seawater.

4.0 RESULTS AND DISCUSSION

Results of the March 1988 survey are presented and discussed in this section. The results are discussed in terms of the background physical oceanographic characteristics of the site at the time of the survey (Sections 4.1 and 4.2). Sludge spreading and mixing are then discussed (Sections 4.3 and 4.4). Impacts of sludge dumping on water quality are presented in Section 4.5. Finally, results of the cetacean and marine turtle survey are presented in Section 4.6.

4.1 OCEANOGRAPHIC CONDITIONS

4.1.1 Water Mass Characteristics

The hydrographic data acquired during the survey represent a high-resolution data set that is ideal for analyses of water mass characteristics and mixing. These data, which include water temperature, salinity, density, dissolved oxygen, and turbidity, were acquired with the high-resolution conductivity/temperature/depth (CTD) profiling system described in Section 3. These data were analyzed in a variety of ways to provide information relevant to the objectives of the survey. The specific hydrographic analyses are listed below:

- Analyses of the vertical density structure as it relates to mixing of sludge plumes discharged at the 106-Mile Site.
- Analyses of temperature/salinity data for identification of shelf water, slope water, and Gulf Stream warm-core eddies in the vicinity of the site.
- Comparisons between shipboard observations of water mass boundaries and those derived from satellite thermal imagery.
- Analyses of background oxygen and turbidity characteristics at the site for comparison with water properties within sludge plumes.
- Oceanographic characterization of the site to allow comparisons with past and future surveys, and which can

ultimately lead to seasonal descriptions of the 106-Mile Site for use in establishing appropriate rates for dumping of sewage sludge.

4.1.1.1 CTD Transect to the 106-Mile Site

During the southbound transit from Narragansett, Rhode Island to the 106-Mile Site on March 1, 1988, a series of CTD profiles was made along a line extending from the edge of the continental shelf to the northern end of the 106-Mile Site (Figure 4-1). The primary objectives of this CTD transect were to (1) test all instrumentation prior to sludge plume surveying, and (2) obtain information on the water column structure and characteristics in the vicinity of the 106-Mile Site. Although only a small amount of time was allocated for this transect survey, the data were useful for comparison with the available maps of large-scale ocean thermal features as derived from satellite thermal imagery.

A summary of the observed conditions along the CTD transect is provided below; Figures 4-2 and 4-3 illustrate the vertical and horizontal characteristics of water properties along the transect.

- A surface layer of relatively cold (5-6°C), low salinity (32.7-33.2 ppt) water of continental shelf origin extended from the shelf to the northern portion of the 106-Mile Site. This observation was consistent with regional interpretations of satellite thermal imagery (see subsection 4.1.1.2).

- At the site, the layer of shelf water lay above normal slope wat-r having maximum temperatures of ≈12°C and maximum salinities of ≈35.3 ppt within a depth range of 100 to 175 m. (See temperature/salinity diagram in Figure 4-2 for identification of water masses.)

- The thickness of the shelf water ranged from 75 m near the edge of the shelf to 50 m at the northern end of the 106-Mile Site. This layer was significantly less dense than the underlying slope water such that a strong pycnocline was established at the boundary between these two water masses.

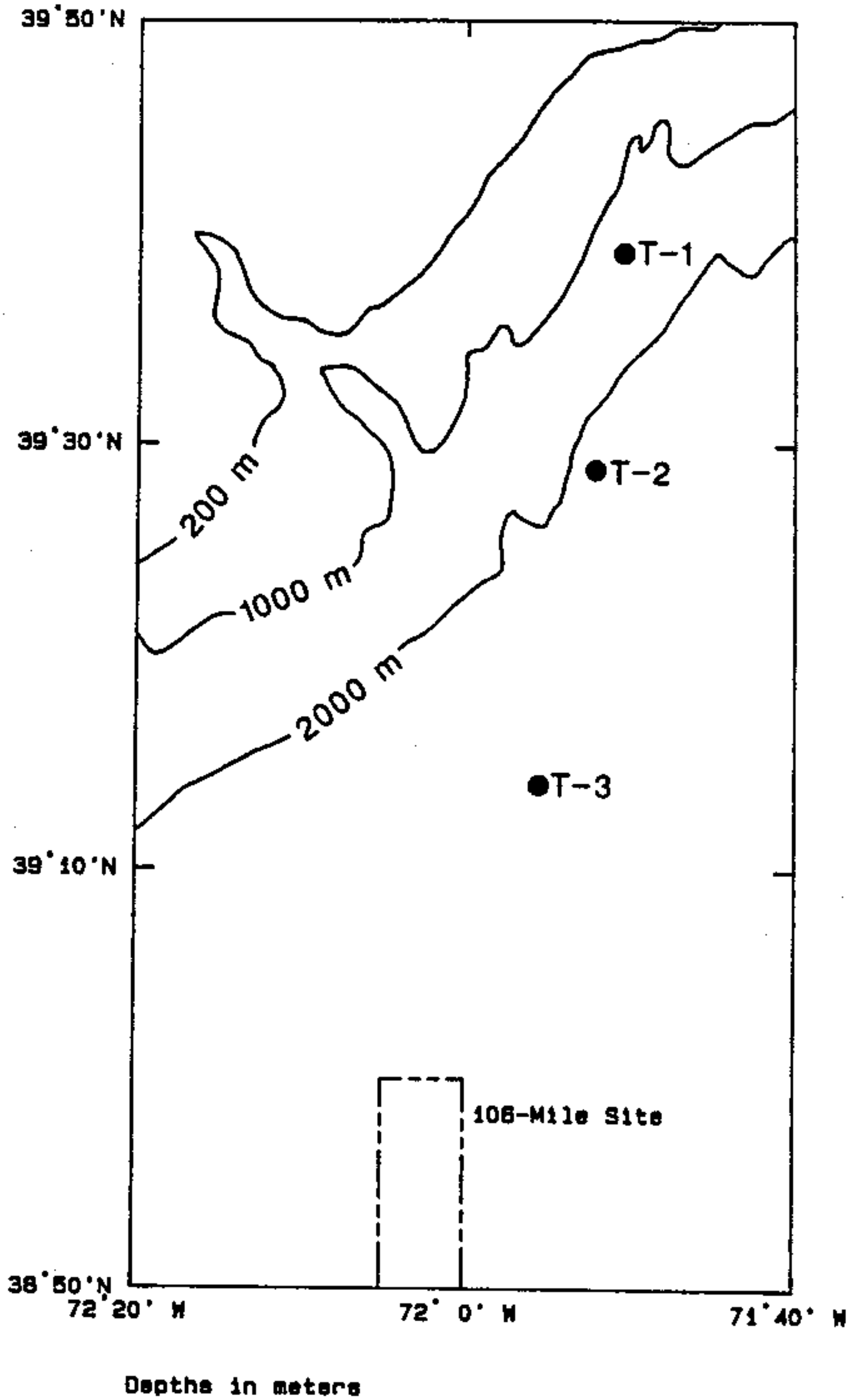


FIGURE 4-1. MAP SHOWING THE LOCATIONS OF THE R/V ENDEAVOR CTD PROFILE STATIONS T-1, T-2, AND T-3, ALONG THE SOUTHBOUND TRANSECT ON MARCH 1, 1988.

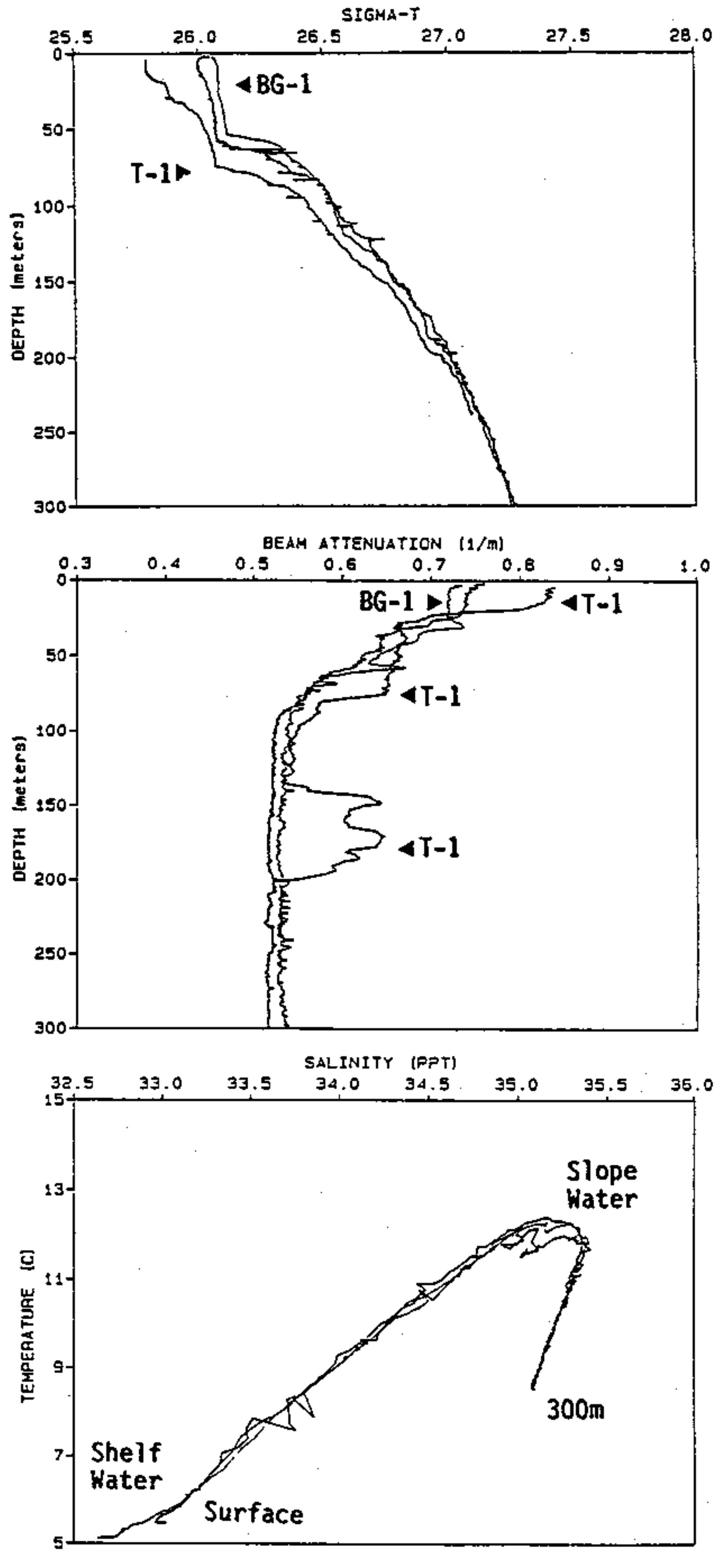


FIGURE 4-2. COMPOSITE OF HYDROGRAPHIC PROFILE RESULTS FROM STATIONS ALONG THE SOUTHBOUND TRANSECT TO THE 106-MILE SITE: SIGMA-T PROFILES (UPPER); BEAM ATTENUATION PROFILES (MIDDLE); TEMPERATURE/ SALINITY CHARACTERISTICS (LOWER).

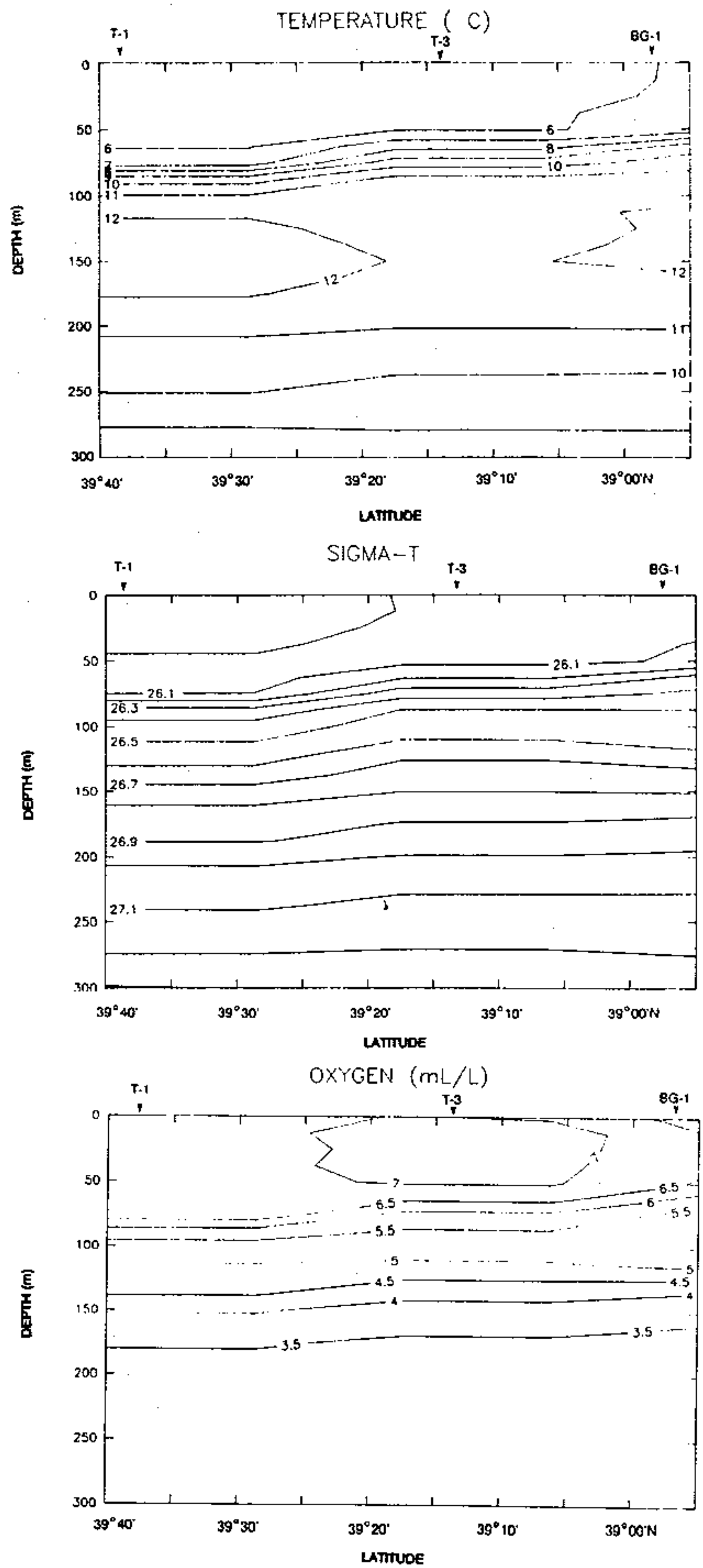


FIGURE 4-3. VERTICAL TRANSECT OF HYDROGRAPHIC PROPERTIES ALONG THE SOUTHBOUND TRANSECT TO THE 106-MILE SITE: TEMPERATURE (UPPER); SALINITY (MIDDLE); DISSOLVED OXYGEN (LOWER).

- Had the shelf water not extended to the 106-Mile Site, the top of the main pycnocline might have been as deep as 150 to 200 m.

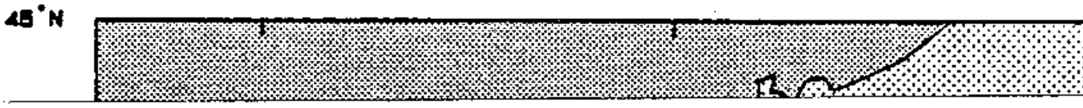
- Dissolved oxygen concentrations were on the order of 7 mL/L in the surface layer of shelf water, whereas values in the slope water (near 150 m depth) were as low as 3.2 mL/L because of biological consumption and considerable time since surface ventilation.

- Beam attenuation (natural turbidity) was highest ($\approx$0.8 m^{-1}) in the surface layer of shelf water; values were generally $\approx$0.5 m^{-1} in the underlying slope water, except for values in excess of 0.6 m^{-1} within a deep layer at the northern most station along the CTD transect.

4.1.1.2 Satellite Thermal Imagery

As indicated in a previous report (EPA , 1988c), the Ocean Frontal Analyses of the U.S. East Coast, prepared by the Marine Climatological Investigation of the National Marine Fisheries Service in Narragansett, Rhode Island, are useful for locating large-scale ocean thermal features in the vicinity of the 106-Mile Site. These weekly, low-resolution analyses provide a composite view of the Gulf Stream position, the location of the shelf water/slope water front, and the positions of warm-core and cold-core eddies formed by the Gulf Stream. These analyses are considerably more useful during winter when there is a strong thermal contrast between the water masses of different origin; in summer, solar warming of the surface layer reduces the contrast between surface water masses.

Figure 4-4 presents a simplified version of the ocean frontal analysis of February 29, 1988, the day before the southbound CTD transect to the 106-Mile Site (see subsection 4.1.1.1). This map illustrates a surface layer of continental shelf water extending well to the south of the continental shelf and beyond the 106-Mile Site. This relatively cold (6 to 8°C) water mass had clearly displaced the warmer (12 to 13°C) slope water in the vicinity of the site. Analysis of additional satellite images indicates that this shelf water event persisted from roughly February 20 to March 20, a period of 4 weeks. Over this time period, a large amount of sludge was dumped at the 106-Mile Site and into this water mass. Although the surface



profiles of current shear from the surface to 1300 m. The drifters were primarily used (in conjunction with dye) to mark the specific portion of the sludge plume that would be the focus of the individual plume survey. Results from the two current measurement techniques are given in the following subsections.

4.1.2.1 XCP Current Profile Results

Two expendable current profiler (XCP) probes were launched during the survey (on March 2 and 3, 1988) to measure current shear in the upper water column. As discussed in the final report for the nearfield monitoring survey in September 1987 (EPA , 1992c), XCPs provide high-resolution measurements of current shear, but they do not provide data on absolute currents. Thus, the "relative" currents measured by the XCP differ from absolute currents by an additive velocity factor that may vary with location (due to the earth's magnetic field) and time (due to the strength of the currents). For the 106-Mile Site, the magnitude of this adjustment should be less than 10 cm/s, based upon discussions with the manufacturer.

The direct measurements of near-surface currents that were obtained from the drifters during the March 1988 survey provide useful data for comparison with the XCP results. As indicated in the following subsection, the drifters at a depth of 5 m generally indicated northerly flow over the 3-day survey period, whereas two drifters at 50 m moved toward the northwest (to the left) of the surface currents. These results indicate that a 7 to 10 cm/s increase in the XCP's north component of current speed is sufficient for matching the absolute currents of the drifters and XCPs. After this adjustment was made, analysis of the XCP profile data reveals the following characteristics of the local current regime during the survey:

- Currents were northward at all levels, although there was considerable shear in direction within the upper 100 m of the water column due to the strong pycnocline.

- Current speeds were less than ≈30 cm/s (0.6 kn) from the surface to depths of 1300 m (the bottom of the profiles).

- Currents were strongest at the surface and within an isothermal layer between 125 and 200 m which corresponded with the slope water mass.

- The surface layer of shelf water was moving northward in association with northward flow throughout the water column (to 1300 m). Hence, if sludge settled beneath the surface mixed layer, its trajectory would still have been northward during the time of the survey.

4.1.2.2 Near-Surface Drifter Results

Current profile data from the XCPs provided real-time information during the plume-tracking operations, but deployment of near-surface drifters proved helpful (1) as visual markers within the specific portion of the sludge plume being tracked, and (2) for determination of currents 5 m below the surface, where XCPs cannot provide good quality data on account of design limitations.

Figure 4-5 presents a summary of drifter results from plume events DB-10 and DB-11 (upper frame), and DB-13 and DB-14 (lower frame). Times and positions are indicated for the launch and recovery of each drifter. In addition to 5-m drogues for all four events, a single 50-m drogue was deployed during plume events DB-10 and DB-14 for analysis of near-surface current shear.

Analysis of the drifter results revealed that

- Near-surface currents were weak and relatively consistent over the 3-day survey (March 2 to 4, 1988). Currents were much less intense than those observed during the nearfield monitoring survey in September 1987.

- Currents at 5 m were directed toward the north or northeast at speeds of 0.6 kn or less.

- Currents at 50 m were directed toward the northwest (to the left of the currents at 5 m) at speeds of roughly 0.2 kn.

The observed northward currents were in agreement with results from XCP current profilers. Both techniques suggest that the surface layer of shelf water was migrating back toward the continental shelf, but additional farfield current measurements would be needed to test this hypothesis.

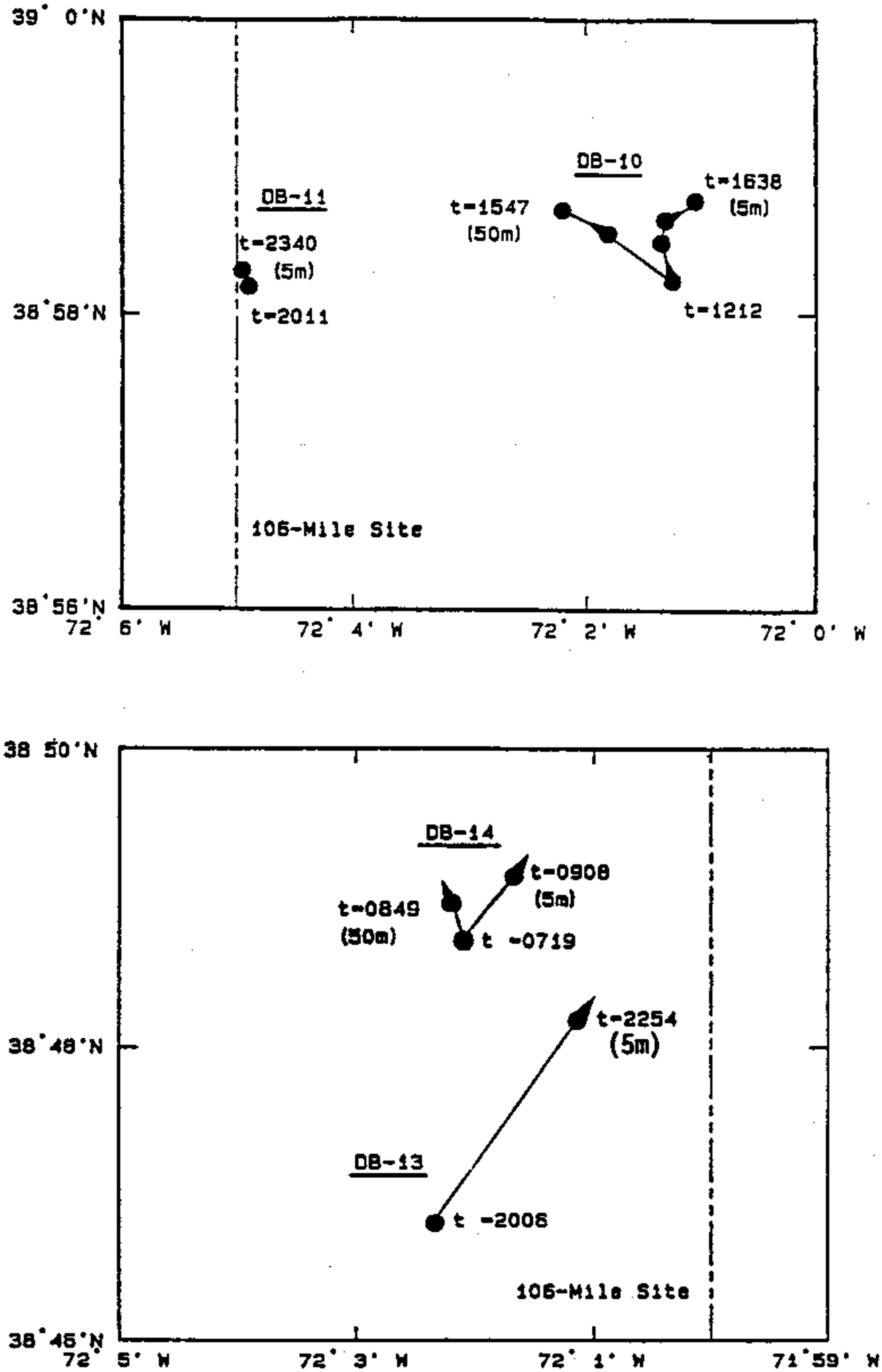


FIGURE 4-5. SUMMARY OF NEAR-SURFACE DRIFTER RESULTS FROM PLUME EVENTS DB-10 AND DB-11 (UPPER) AND DB-13 AND DB-14 (LOWER) DURING THE MARCH SURVEY AT THE 106-MILE SITE. TIMES ARE GIVEN FOR THE START AND END POSITIONS OF EACH TRAJECTORY.

4.2 BACKGROUND WATER QUALITY

Water collected at two stations located within the boundaries of the 106-Mile Sludge Disposal Site was analyzed for contaminants for which there are water quality criteria (Table 2-1), iron, total suspended solids, *C. perfringens*, and selected trace metals in the particulate phase to provide background water quality information at the site. Station BG-1, located in the northeast corner of the site, was sampled at 5, 60, and 98 m for metals, WQC parameters, and TSS just prior to sludge dumping in the same area. Station BG-2, located near the center of the site, south of known dumping activities, was sampled at 5 and 48 m for the same parameters. Samples for analysis of organic compounds were obtained at a single depth at each station, at 65 m at BG-1 and 16 m at BG-2. The hydrographic data from these stations indicate that all the background samples, except for those obtained at 98 m at BG-1, were collected in the layer of shelf water intruding over the site during the survey. The sample from 98 m was located within the permanent pycnocline.

Concentrations of metals in background water at the site were generally 10 to 1000 times lower than the water quality criteria (Table 4-1). Ambient concentrations of organic compounds were also low. Dieldrin and a Cl_6PCB isomer were detected in one of the two duplicate samples from BG-1; Endosulfan I and a Cl_7PCB isomer were found in one of two samples from BG-2. No other organic compounds were detected. PCBs showed no distinct elution pattern that could be matched to any commercial PCB formulation. No *C. perfringens* spores were found in any of the 10 samples collected at these stations. The TSS concentrations were low (0.32 to 0.80 mg/L). Contaminant concentrations are compared to those found during the 1987 survey in Table 4-2.

Contaminant and TSS distribution in the background revealed several results that may be related to the farfield fate of sludge dumped at the site:

- TSS concentrations at the surface and at 98 m at station BG-1 were 50 percent higher than those found at 60 m, and were also 50 percent higher than those found at

TABLE 4-1. BACKGROUND WATER QUALITY MEASUREMENTS IN SEAWATER AT THE 106-MILE SITE, MARCH 2-4, 1988.

Parameter	Concentration Range[a]	EPA Marine Water Quality Criteria Chronic	Acute
Metals	(µg/L)		
Arsenic, total	0.93-1.52	2,319[a]	
Cadmium	0.018-0.024	9.3	43
Chromium, total	0.13-0.15	50[a]	1,100[a]
Copper	0.19-6.41[b]	2.9	2.9
Lead	0.056-3.9[b]	5.6	140
Mercury	0.003-0.008	0.025	2.1
Nickel	0.26-0.30	8.3	75
Selenium	<.04	54	410
Silver	0.002-0.044[c]	-	2.3
Zinc	0.22-16.1[b]	86	95
Organic Compounds	(ng/L)		
Aldrin	ND	-	1,300
Dieldrin	0.60	1.9	710
p,p'-DDT	ND	1	130
p,p'-DDE	ND	-	-
Endosulfan I	0.15	8.7	34
Endosulfan II	ND		
Endrin	ND	2.3	37
Heptachlor	ND	3.6	53
Total PCB	ND- 0.25	30	10,000
Total Suspended Solids	(mg/L)		
	0.32 to 0.80[b]	-	-
C. perfringens	(#/100 mL)		
	0		-

ND = Not Detected.

[a]Values for arsenic V and chromium VI are reported.

[b]One high value from 98 m with no confirming duplicate was obtained. Highest concentrations without this sample were Cu, 1.68 µg/L; Pb, 3.8 µg/L; Zn, 3.8 µg/L; and TSS 0.66 mg/L.

[c]The extraction effeciency was only 50 percent; results are not corrected for this efficiency.

[d]Highest values were in the particle maximum located in the pycnocline.

TABLE 4-2. COMPARISON OF BACKGROUND WATER QUALITY MEASUREMENTS AT THE 106-MILE SITE, SEPTEMBER 1987 and MARCH 1988.

Parameter	Range	
	September 1987[a]	March 1988
Metals (µg/L)		
Arsenic, total	0.93-1.29	0.93-1.52
Cadmium	0.013-0.024	0.018-0.024
Chromium, total	0.11-0.15	0.13-0.15
Copper	0.17-0.23	0.19-6.41
Lead	0.033-0.12	0.056-3.9
Mercury	0.004-0.013	0.003-0.008
Nickel	0.23-0.27	0.26-0.30
Selenium	<.03	<.04
Silver	0.002-0.020	0.002-0.044
Zinc	0.02-0.20	0.22-16.1
Organic Compounds ng/L		
Aldrin	ND	ND
Chlordane	ND	NA
Dieldrin	ND	ND-0.60
p,p'-DDT	ND	ND
p,p'-DDE	ND	ND
Endosulfan I	ND	ND-0.15
Endosulfan II	NA	ND
Endrin	ND	ND
Heptachlor	ND	ND
Total PCB	ND-0.066	ND-0.25
α-BHC	ND-9.4	NA
δ-BHC	ND-2.5	NA
Total Suspended Solids (mg/L)		
	0.16 to 0.93	0.32 to 0.80
C. perfringens (#/100 mL)		
	0	0

NA = Not Analyzed.

ND = Not Detected.

a EPA (1992c).

station BG-2. TSS concentrations at 60 m at BG-1 and at 48 m at BG-2 are similar and also similar to those found at the site during the previous survey (Figure 4-6).

- Copper and iron concentrations in surface waters were higher at station BG-1 than at station BG-2, with copper approaching water quality criteria at BG-1. Copper and iron concentrations at 60 m at BG-1 and at 48 m at BG-2 were lower than the surface, similar to each other, and also similar to those found at the site during the previous survey (Figure 4-6). Highest concentrations of copper and iron were found at the pycnocline (98 m) at station BG-1. Copper exceeded the water quality criterion at this depth.

- Lead and zinc, also analyzed in the same set of samples, had similar distributions to those of copper and iron, but concentration differences were not as pronounced as those for copper and iron.

- Other metals for which there are water quality criteria (silver, arsenic, cadmium, chromium, nickel, selenium, and mercury), analyzed only at 60 m at BG-1 and at 5 and 48 m at BG-2, had expected background concentrations and expected relative concentrations (Table B-3, Appendix B).

Quality control information indicated that the elevated metals concentrations were not the result of sampling artifacts or laboratory contamination. Therefore, the data suggest some residual sludge fraction resulting from previous dumping events may be present in the northern half of the site. Copper, iron, lead and zinc, being the most sensitive sludge tracers, show the most noticeable concentration differences observed. Other metal and organic contaminants, TSS, and C. perfringens did not reveal any additional information regarding the potential contamination of the background stations from sludge. The data from this survey were not sufficient to determine whether the apparent background water contamination is from a discrete plume remaining in the surface water or from an area-wide increase in pollutant concentrations in the surface waters.

4.3 BARGE DUMPING INFORMATION

Barges vary greatly in terms of size, sludge capacity, dumping method, maximum dumping rate, and method of propulsion (unpowered barges

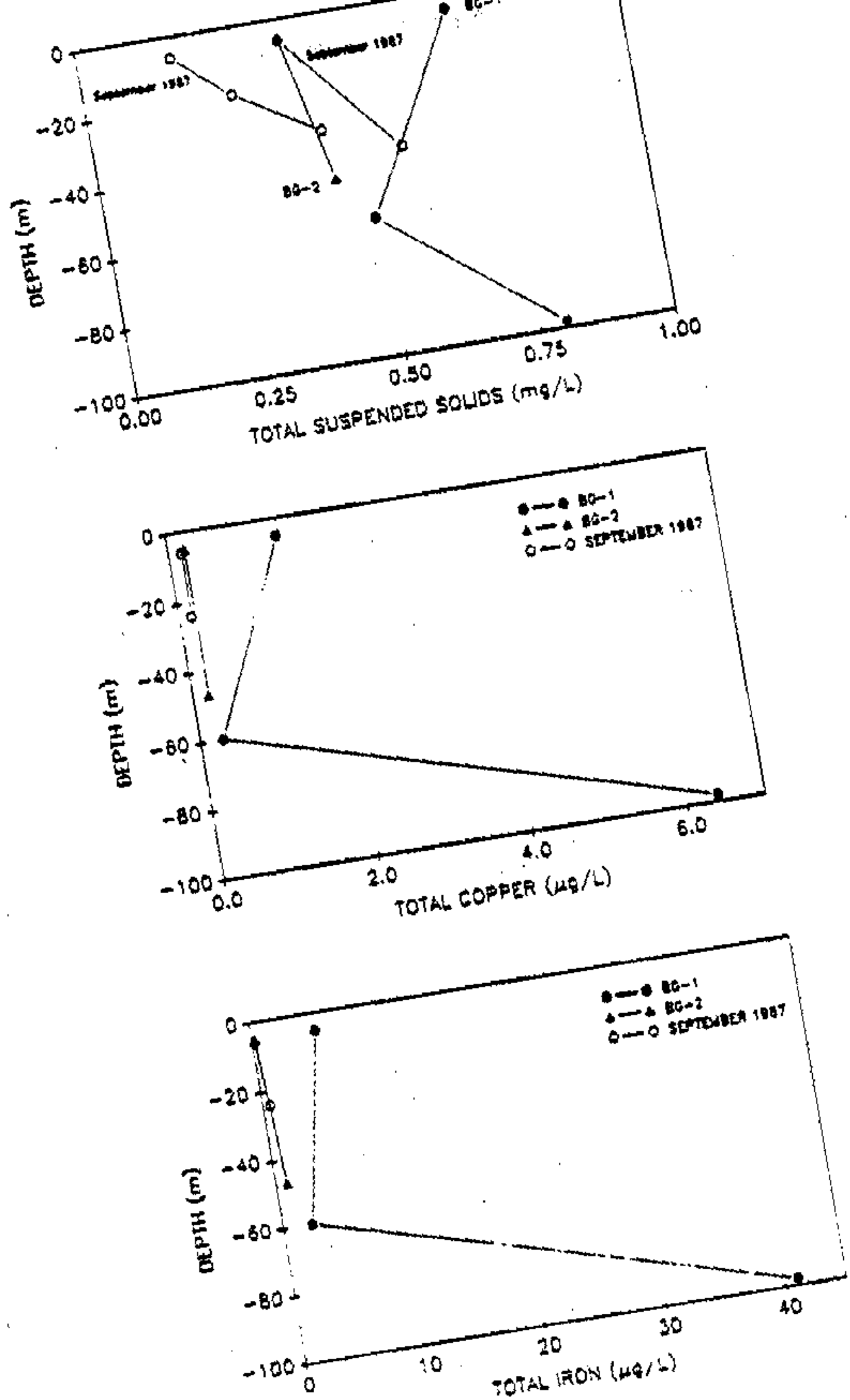


FIGURE 4-6. COMPARISON OF DATA FROM BACKGROUND STATIONS SAMPLED AT THE 106-MILE SITE IN SEPTEMBER 1987 AND MARCH 1988; TOTAL SUSPENDED SOLIDS (UPPER), TOTAL COPPER (MIDDLE), AND TOTAL IRON (LOWER).

versus self-powered tankers) (EPA , 1992d). Most of the above factors probably affect the initial, wake-induced dilution of sludge immediately behind the barges, but a large number of nearfield surveys would be required to quantify the effects of the various parameters. The results from the nearfield survey in September 1987 illustrated that plume settling and dispersion within the first 4 h after dumping was generally the same for the four plumes surveyed, although the barges varied considerably in terms of size, sludge volume, dumping method, and barge speed (EPA , 1992c). These results suggested that barge configuration may have a smaller effect upon initial sludge dilution than other factors such as dumping rate, sludge characteristics, water column stratification, and oceanographic mixing conditions.

To further investigate the degree to which barge characteristics have a significant effect upon the nearfield behavior of sludge plumes, dumping information was compiled for each of the sludge dumping operations surveyed during the period of the survey from March 2 to 4, 1988. Table 4-3 presents a summary of the barges for each of the six plume events (DB-10 through DB-15), including barge dumping methods, sludge capacity of each barge, and the origin of the sludge transported by each barge. Events DB-10 and DB-14 were associated with sludge barges from the New York City Department of Environmental Protection (NYCDEP); both barges (Lemon Creek and Spring Creek) carried sludge from the Wards Island facility. Dumping events DB-12 and DB-13 were associated with barges carrying sludge from the Passaic Valley Sewerage Commission. The sludge for events DB-11 and DB-15 originated at Middlesex County and Nassau County, respectively.

With the exception of the small (180 ft), self-powered tanker OBI-IV, the other barges ranged from 266 ft (Weeks 701) to 380 ft (NYCDEP barges) and were towed to the site by tugs. Note that the sludge capacity of the OBI-IV (200,000 gal) is roughly 18 times less than the capacity of a single NYCDEP barge.

Table 4-4 presents information for the six dumping events listed in Table 4-3. Sludge volumes, dumping times, and plume lengths were obtained directly from the Ocean Dumping Notification Forms that are submitted to EPA following each dumping operation. Average barge speed and average dumping rates were calculated from the basic information of volume,

TABLE 4-3. SUMMARY OF DUMPING METHODS, SLUDGE CAPACITY, AND ORIGIN OF SLUDGE FOR EACH VESSEL DUMPING SLUDGE AT THE 106-MILE SITE DURING THE PERIOD MARCH 2-4, 1988.

Survey	Vessel	Type	Dumping Method	Sludge Capacity (million gal)	Origin of Sludge
DB-10	Lemon Creek	Barge	Bottom Dump	3.5	Wards Island (NYC DEP)
DB-11	Leo Frank	Barge	Bottom Dump	1.3	Middlesex County
DB-12	Weeks 701	Barge	Bottom Dump	1.5	Passaic Valley
DB-13	Morris Berman	Barge	Pump Out	2.8	Passaic Valley
DB-14	Spring Creek	Barge	Bottom Dump	3.5	Wards Island (NYC DEP)
DB-15	OBI-4	M/V	Pump Out	0.2	Nassau County

TABLE 4-4. SUMMARY OF DUMPING INFORMATION FOR BARGES DUMPING SLUDGE AT THE 106-MILE SITE DURING THE PERIOD MARCH 2-4, 1988.

Survey Date	DB-10 3/2	DB-11 3/2	DB-12 3/3	DB-13 3/3	DB-14 3/4	DB-15 3/4
Tug	Sheila Moran	Emily S	Elizabeth	Kate	Esther Moran	-
Barge	Lemon Creek	Leo Frank	Weeks 701	Morris Berman	Spring Creek	OBI-4
Sludge Volume (gal)[a]	3,366,225	1,290,114	1,424,340	2,928,206	3,515,835	200,000
Barge Speed (kn)[b]	5.2	7.3	10.5	7.3	4.6	3.9
Dumping Time (h)[a]	4.0	1.5	0.6 (0.2)[d]	3.8	4.0	1.7
Plume Length (nmi)[a]	21.0	11.0	6.3 (1.7)[c]	27.8	18.5	6.6
Volume Dumping Rate (gal/min)[b]	14,026	14,335	40,695 (118,695)[d]	12,843	14,649	1,961
Effective Dumping Rate (gal/ft)[b]	26.4	19.3	37.2 (137.9)[d]	17.3	31.3	5.0

[a]Data provided on Ocean Dumping Notification Forms.
[b]Calculated from data provided on Ocean Dumping Notification Forms.
[c]Estimates based upon observations from survey vessel and aerial reconnaissance.
[d]Calculated from barge speed of 10.5 kn and plume length of 1.7 nmi.

dumping time, and plume length. Sludge volumes for the individual barges ranged from 200,000 to roughly 3.5 million gallons; barge speeds varied from 3.9 to 10.5 kn. With the exception of the Weeks 701, dumping times ranged from 1.5 to 4 h; the Weeks 701 dumped its entire load of sludge in 0.6 h.

Average volume dumping rates (in gal/min) have been determined from the sludge volume divided by the dumping time. For the NYCDEP barges (Lemon Creek and Spring Creek), the Leo Frank, and the Morris Berman, volume dumping rates were between 12,800 and 14,700 gal/min, less than the maximum court-ordered rate of 15,500 gal/min. The OBI-4, a vessel which pumps sludge from its holding tanks, has a maximum pumping rate of approximately 2,000 gal/min as indicated in Table 4-4. Figure 4-7 illustrates the variations in volume dumping rates and barge speeds for each of the dumping events surveyed.

The average volume dumping rate of the Weeks 701, 40,695 gal/min, was nearly 3 times the court-ordered rate of 15,500 gal/min, as determined from the volume of the sludge and the dumping time provided on the Ocean Dumping Notification Form. Measurements of this sludge plume during the nearfield survey (event DB-12) revealed, however, that both the position and the length of this plume were different from those noted on the Ocean Dumping Notification Form. The direct measurements of the plume exhibited an extremely wide and concentrated plume that was roughly 1.7 nmi long; with a barge speed of 10.5 kn, this would result in a dumping time of 0.2 h and a volume dumping rate of nearly 120,000 gal/min.

The survey of barge characteristics (EPA , 1992d) revealed that the Weeks 701 and Weeks 702 could dump their entire load in 30 minutes or less, such that dumping rates would reach 140,000 gal/min. The exact rate at which the Weeks 701 dumped its load on March 3, 1988, cannot be determined from the available information, but the above evidence suggests that the rate was 3 to 8 times the court-ordered rate of 15,500 gal/min. The characteristics of this plume, which are presented in subsection 4.4, support the presumption of high dumping rate for the Weeks 701.

Estimates of the effective dumping rate, expressed in units of gallons per foot of plume length, for each of the six dumping events are given in Table 4-4; the relationship between volume dumping rates and effective dumping rates is demonstrated in Figure 4-7. It has been shown

(EPA , 1992d) that the effective dumping rate (in gal/ft) has a greater effect upon the nearfield behavior of sludge plumes than the volume dumping rate, expressed in units of gallons per minute. With a maximum court-ordered volume dumping rate of 15,500 gal/min and a minimum allowable barge speed of 3 kn, the implied maximum effective dumping rate is 51 gal/ft. As indicated in Table 4-4, the two NYCDEP barges (events DB-10 and DB-14), the Leo Frank (DB-11), and the Morris Berman (DB-13) had effective dumping rates between 17 and 32 gal/ft; the OBI-IV had a low rate of 5.0 gal/ft on account of its slow pumping rate.

In contrast to the other dumping events, the Weeks 701 (event DB-12) had a high effective dumping rate (between 37 and 138 gal/ft) in spite of its high barge speed (10.5 kn). Direct observations of the plume from the Weeks 701 (see subsection 4.4) support the assumption that the effective dumping rate for this barge event (≈138 gal/ft) may have been 8 times the rate of the Morris Berman (≈17 gal/ft) and 28 times the rate of the OBI-IV (5 gal/ft).

This analysis of dumping rates suggests that the three categories of sludge plumes were surveyed during the March 1988 survey at the 106-Mile Site:

- A highly concentrated plume from the Weeks 701 with an effective dumping rate of over 100 gal/ft
- Moderate plumes from the NYCDEP barges, the Leo Frank, and the Morris Berman, with effective dumping rates of 17 to 32 gal/ft
- A weak plume from the OBI-IV with an effective dumping rate of 5 gal/ft.

4.4 SLUDGE PLUME BEHAVIOR

4.4.1 Vertical and Horizontal Spreading

To determine the short-term mixing and dispersion characteristics of sludge plumes that were dumped at the 106-Mile Site during the survey, it is first necessary to quantify their spatial scales and the rates at which they vary. The following sections present analyses of sludge plume thickness and width, as determined from (1) the shipboard profiling with the CTD/transmissometer system, and (2) aerial photography.

4.4.1.1 Vertical Spreading

Vertical profile measurements within the individual sludge plumes were effective for determining the short-term vertical distribution of sludge throughout the upper water column. As demonstrated during the nearfield monitoring survey in September 1987, the optimum parameter for monitoring vertical plume behavior was in situ turbidity, as measured by the beam transmissometer mounted on the CTD sensor package. Due to the high total suspended solids (TSS) content of the sludges, it was possible to detect sludge at very high dilutions and for many hours after dumping.

Table 4-5 illustrates the range of TSS concentrations for the sludges surveyed during this survey and compares them to those of the previous (September 1987) survey at the 106-Mile Site. For each plume event (DB-1 through DB-4 for the September survey, and DB-10 through DB-15 for the March survey), the origin of the sludge and the mean TSS concentration of the sludge, as estimated by Santoro and Fikslin (1987), are indicated. The mean TSS concentration of the sludge from Passaic Valley, 79,965 mg/L, is clearly much greater than the TSS concentration of the other sludges (roughly twice that of the Middlesex County sludge and 4 times that of Wards Island and Nassau County sludges). As expected, sludge from Passaic Valley was considerably easier to track with the in situ transmissometer than sludge from other facilities.

The results from the individual turbidity profiles were most useful for analyses of plume thickness and identification of maximum sludge concentrations within the water column. Plume thickness, defined as the maximum observed depth of sludge penetration, provides a measure of short-term settling of sludge. Figure 4-8 presents a composite time series of observed plume thickness for sludge plumes surveyed in this survey and compares the data to the previous surveys.

The previous survey produced the following conclusions about vertical dispersion under summer oceanographic conditions:

TABLE 4-5. SUMMARY OF TOTAL SUSPENDED SOLIDS CHARACTERISTICS FOR THE SLUDGES SURVEYED DURING THE SEPTEMBER 1987 AND MARCH 1988 SURVEYS AT THE 106-MILE SITE. TSS ESTIMATES FROM SANTORO AND FIKSLIN (1987).

Plume Event	Survey Date	Treatment Facility	Mean TSS (mg/L)
DB-1	9/87	Wards Island (NYCDEP)	18,067
DB-2	"	Wards Island (NYCDEP)	18,067
DB-3	"	Port Richmond (NYCDEP)	26,471
DB-4	"	26th Ward	25,217
DB-10	3/88	Wards Island (NYCDEP)	18,067
DB-11	"	Middlesex County	33,496
DB-12	"	Passaic Valley	79,965
DB-13	"	Passaic Valley	79,965
DB-14	"	Wards Island (NYCDEP)	18,067
DB-15	"	Nassau County	17,462

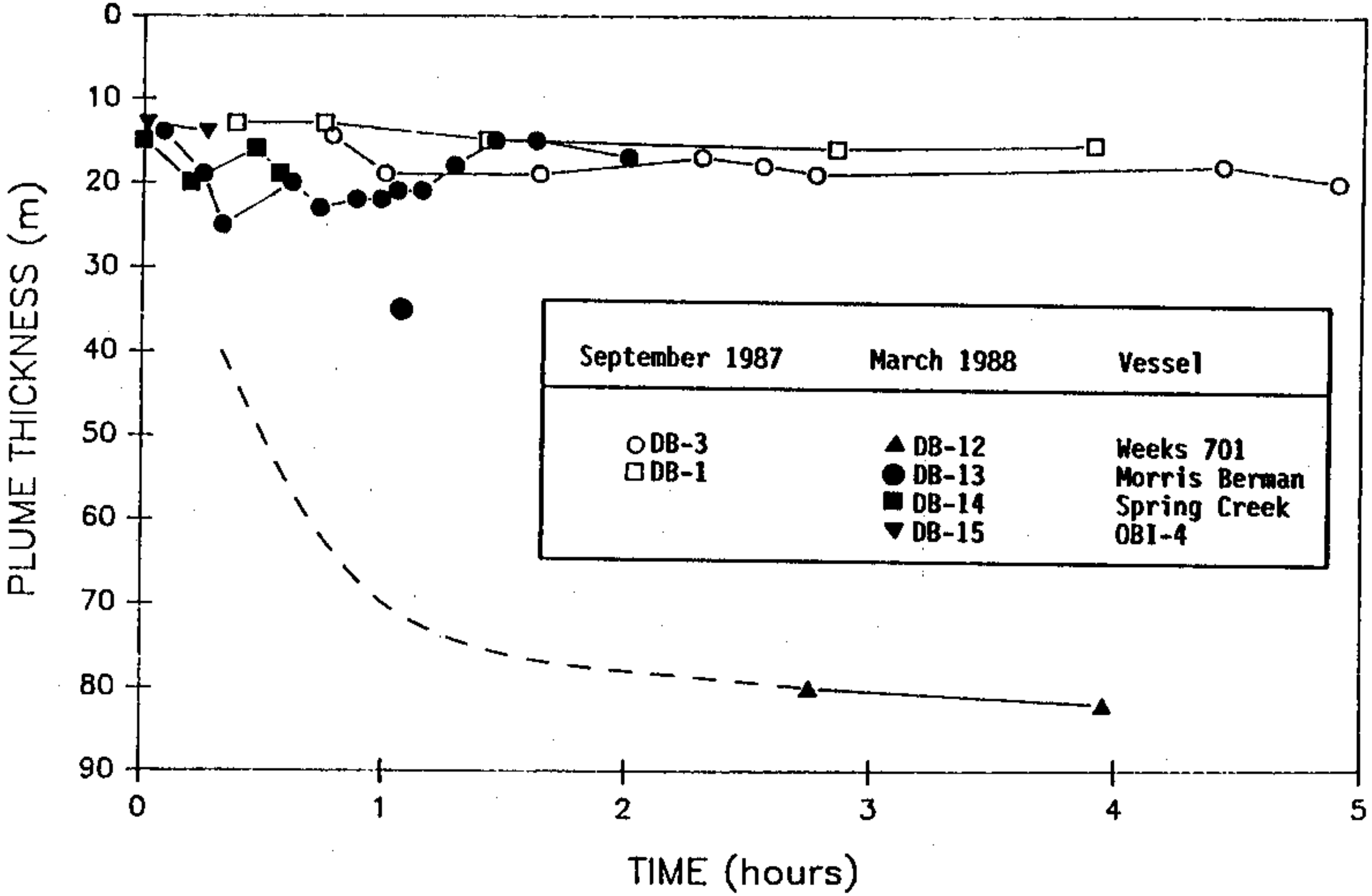


FIGURE 4-8. TIME SERIES PLOT OF PLUME THICKNESS FOR PLUMES SURVEYED IN SEPTEMBER 1987 (OPEN SYMBOLS) AND MARCH 1988 (SOLID SYMBOLS).

- Initial (0 to 5 min) mixing within the wake of the barge resulted in sludge penetration to 10 to 15 m, the approximate draft of the barges.

- Vertical mixing processes resulted in sludge penetration to roughly 18 m four hours after dumping. This depth corresponded with the top of the seasonal pycnocline.

- There was no indication that sludge settled to depths greater than 20 m, with penetration beneath the seasonal pycnocline.

- The results from four plume surveys in summer were similar, although four different barges and three different sludge types were surveyed.

The profile results from this survey, which are indicated by solid symbols in Figure 4-8, illustrate many of the settling (thickness) characteristics similar to those observed during the previous survey. The majority of the plume thickness measurements during the first 2 h of plume events DB-13, DB-14, and DB-15 exhibited values ranging from 15 to 25 m, in agreement with the summer results. Plumes from the Spring Creek and the Morris Berman were surveyed during both seasons; the Spring Creek carried sludge from Wards Island both times, and the Morris Berman carried sludge from Port Richmond (September) and Passaic Valley (March).

The 35-m thickness observed 1.2 h after dumping for plume event DB-13 most likely represents the settling of a heavy fraction of Passaic Valley sludge on the axis of the plume. The horizontal, cross-axis scale of this segment of the plume must have been 10 m or less, and/or this feature must have been short-lived because this structure was not sampled again over the next 2 h. Nevertheless, this observation illustrates that, during the winter survey, a fraction of the sludge from plume event DB-13 penetrated below the 20 m level that was observed for summer plumes.

The most striking difference between the summer and winter plume thickness results presented in Figure 4-8 was the deep penetration of Passaic Valley sludge from the Weeks 701 during plume event DB-12. Although the nearfield measurements did not begin until well after sludge dumping, the direct observations revealed plume thicknesses of roughly 80 m between 2.7 and 4 h after dumping. These thicknesses were (1) greater than all other plume observations during both the winter and summer surveys, and (2) greater than the mixed-layer depth, such that sludge had clearly penetrated the upper boundary of the pycnocline which was situated at 50 m. Thus, Passaic Valley sludge dumped during plume event DB-12 settled much deeper than Passaic Valley sludge dumped during plume event DB-13. It is believed that the deep penetration of plume DB-12 was due to the extremely high dumping rate (40,000 to 118,000 gal/min) of the Weeks 701, as discussed in subsection 4.3. This enhanced settling may be caused by increased flocculation when sludge is dumped rapidly and initial dilutions are low (Lavelle et al., 1988).

To summarize, the winter observations of plume thickness have demonstrated the following short-term (0 to 4 h) characteristics of sludge plumes:

- Plumes generally remained within the upper 25 m of the water column during summer and winter provided that dumping rates were 15,500 gal/min or less.
- Winter plumes did not reach the base of the mixed layer (50 to 150 m) except when dumping rates were much greater than 15,500 gal/min.
- Plume thickness was highly dependent upon dumping rate; sludge has been observed to penetrate the pycnocline within the first 3 h after dumping when sludge is dumped faster than the court-ordered rate of 15,500 gal/min.
- Barge configuration, dumping method, sludge characteristics, and seasonal variations in water column stratification all had a smaller effect upon sludge settling than the dumping rate.

4.4.1.2 Horizontal Spreading

Plume width data were obtained for plume events DB-10, DB-11, and DB-12 during the survey. These estimates of plume width were determined from (1) horizontal profiles of turbidity using the shipboard profiling with the CTD/transmissometer system, and (2) aerial photographs of the surface turbidity boundaries of the plume. These analyses were conducted in the same manner as the analyses of plume width from the September 1987 survey data (EPA , 1992d).

For plume event DB-10, analysis of aerial photographs provided accurate estimates of plume width during the first 16 min following dumping. As indicated in Figure 4-9, plume widths increased from 29 to 163 m during this period following dumping. As observed during the summer (September 1987) survey, the rate of horizontal spreading was greatest during the first few minutes when mixing was active due to turbulence in the wake of the barge.

Plume width estimates from roughly 1 to 3 h following dumping for plume event DB-10 were obtained from the horizontal profiles of transmissometry data. As indicated in Figure 4-9, plume widths increased from roughly 240 to 700 m during this time period. Both the magnitude and the rate of spreading for plume event DB-10 were similar to the observations during September 1987; the plumes in the summer exhibited widths between 175 and 350 m one hour after dumping.

During plume event DB-11, which began at 2011 hours on March 2, 1988, a total of 18 horizontal tows were conducted during darkness. From real-time, on-board analysis of the profile results, it was determined that the dumping rate varied significantly along the barge track, and that the dumping rate must have been significantly (5 to 10 times) less than 15,500 gal/min rate at the location of the initial (time 0) profiling transects. After low turbidity values had been observed during the first few plume transects, the survey plan was modified in order to acquire profile data from another location along the plume. Because the horizontal profile data from plume event DB-11 did not provide a useful 2 to 3 h time series of plume width from a single location within the plume, the results from event DB-11 are not shown in Figure 4-9.

Plume width estimates are also lacking for the first 2 h following dumping for plume event DB-12 because the Weeks 701 had dumped its load before the survey vessel had reached the position of the barge (outside of the site). Plume width oata from event DB-12, acquired by the in situ transmissometer system, are presented in Figure 4-9. These data illustrate that plume widths increased from roughly 500 to 1200 m during the period from 2 to 4 h following dumping. The results are quite similar to those from plume event DB-10, which is surprising because the rate of dumping for plume event DB-12 (40,000 to 118,000 gal/min) was much greater than the dumping rate for plume event DB-10 (≈14,000 gal/min).

To summarize, the winter observations of plume width demonstrated the following short-term (0 to 4 h) characteristics of sludge plumes:

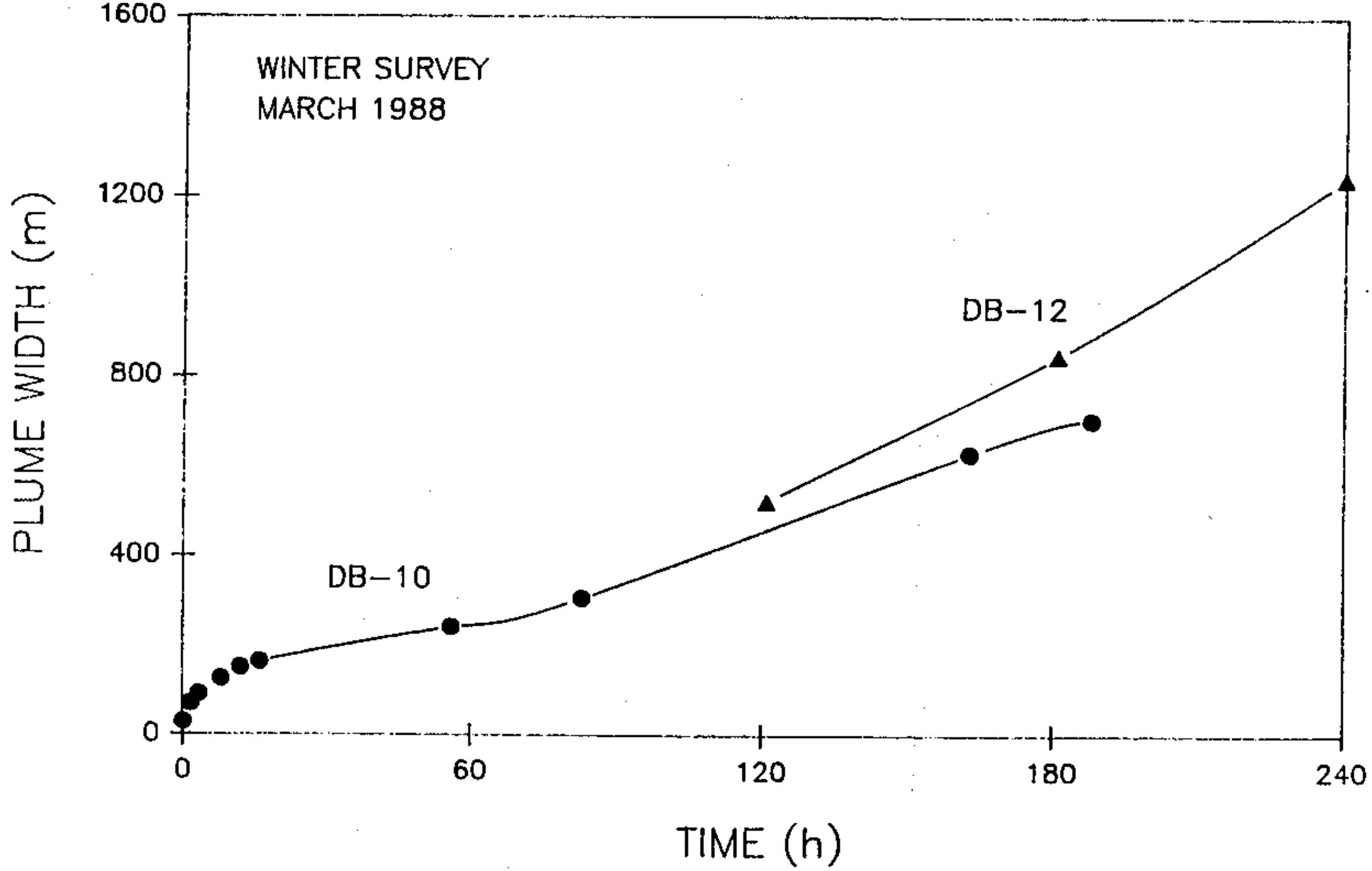


FIGURE 4-9. TIME SERIES PLOT OF PLUME WIDTH FOR PLUME EVENTS DB-10 AND DB-12 SURVEYED IN MARCH 1988. DATA WERE DERIVED FROM AERIAL PHOTOGRAPHY AND IN SITU PROFILE MEASUREMENTS.

- Plume widths and the rate of horizontal spreading during winter were similar to those observed during the summer (September 1987) survey. However, wind and wave conditions during the winter survey were so mild that the winter mixing conditions were not unlike those observed during summer; near-surface current shear was also much less intense during the winter survey.

- Plume widths did not vary according to barge configuration, dumping method, sludge characteristics, or water column stratification; surface mixing conditions (winds and waves) and sludge dumping rates are expected to have the most significant effect upon horizontal spreading rates.

- Horizontal spreading rates were greatest (30 to 40 cm/s) during the first few minutes after dumping due to turbulent mixing within the wake of the barge; between 1 and 4 h after dumping, spreading rates were 5 to 10 cm/s.

However, these survey results did not represent active winter mixing conditions (high winds and waves) that would result in greater rates of plume spreading and dilution. In addition, neither the summer (September 1987) nor the winter (March 1988) survey was conducted when a warm-core Gulf Stream eddy was present at the site. During such periods, currents are much stronger and the rate of plume dilution may consequently be much greater than demonstrated by the two recent nearfield surveys.

4.4.2 Sludge Dilution and Transport

Analyses of the sludge plume measurements made during the survey revealed that sludge plumes generally have a core of relatively concentrated sludge, at least during the first 4 to 8 h after dumping. Because of the oceanographic mixing processes (e.g., winds, waves, and current shear) that cause plume advection and dispersion, this core was not always situated at mid-depth within the plume, nor along the linear axis of the plume. Likewise, the frequency distribution of sludge concentrations within the plume was far from Gaussian.

Although the behavior of the relatively concentrated core of the plumes was difficult to monitor, let alone predict, it is this core that is of greatest concern to EPA because ocean dumping regulations specify that concentrations of contaminants in parcels of ocean-dumped sludge may not exceed water quality criteria 4 h after dumping, or at any time outside of the designated site. Estimates of plume-averaged dilution, based upon known dumping rates and direct measurements of plume width and thickness, are inappropriate for testing compliance with water quality criteria because they overestimate sludge dilution within the core of the plumes.

The results from the survey illustrated that plume-averaged dilutions were much greater than dilutions of concentrated parcels of sludge within the core of plumes; the ratio of plume-averaged dilution to parcel dilution at 0, 1 and 2 h after dumping was approximately 2.5, 10 and 33, respectively. Figure 4-10 illustrates this difference between plume-averaged dilution and parcel dilution for plume event DB-3 surveyed in September 1987. The parcel dilutions were derived from trace metal analyses of water samples collected within the concentrated core of the plume (EPA , 1992c).

Based upon the need to determine the rate of sludge dilution within the core of the plumes, this section presents analyses of dilution within the sludge plumes monitored during the nearfield survey in March 1988 and compares the results to those of the previous survey. Subsection 4.4.2.1 presents an analysis of dilution based upon vertical and horizontal profiles of turbidity acquired using the in situ profiling system. Subsection 4.4.2.2 presents results of analyses of dilution based upon trace metal concentrations from discrete water samples collected within the plumes. These results are followed by a discussion of the horizontal transport of sludge plumes monitored during the survey (section 4.4.2.3).

4.4.2.1 Dilution Based on Transmissometry Data

Analyses of the transmissometry data focused on determination of the rate of dilution within the core of the plumes. Two steps were required to achieve this objective:

1. Identification of the most concentrated portion of the plume on each vertical profile and horizontal tow.

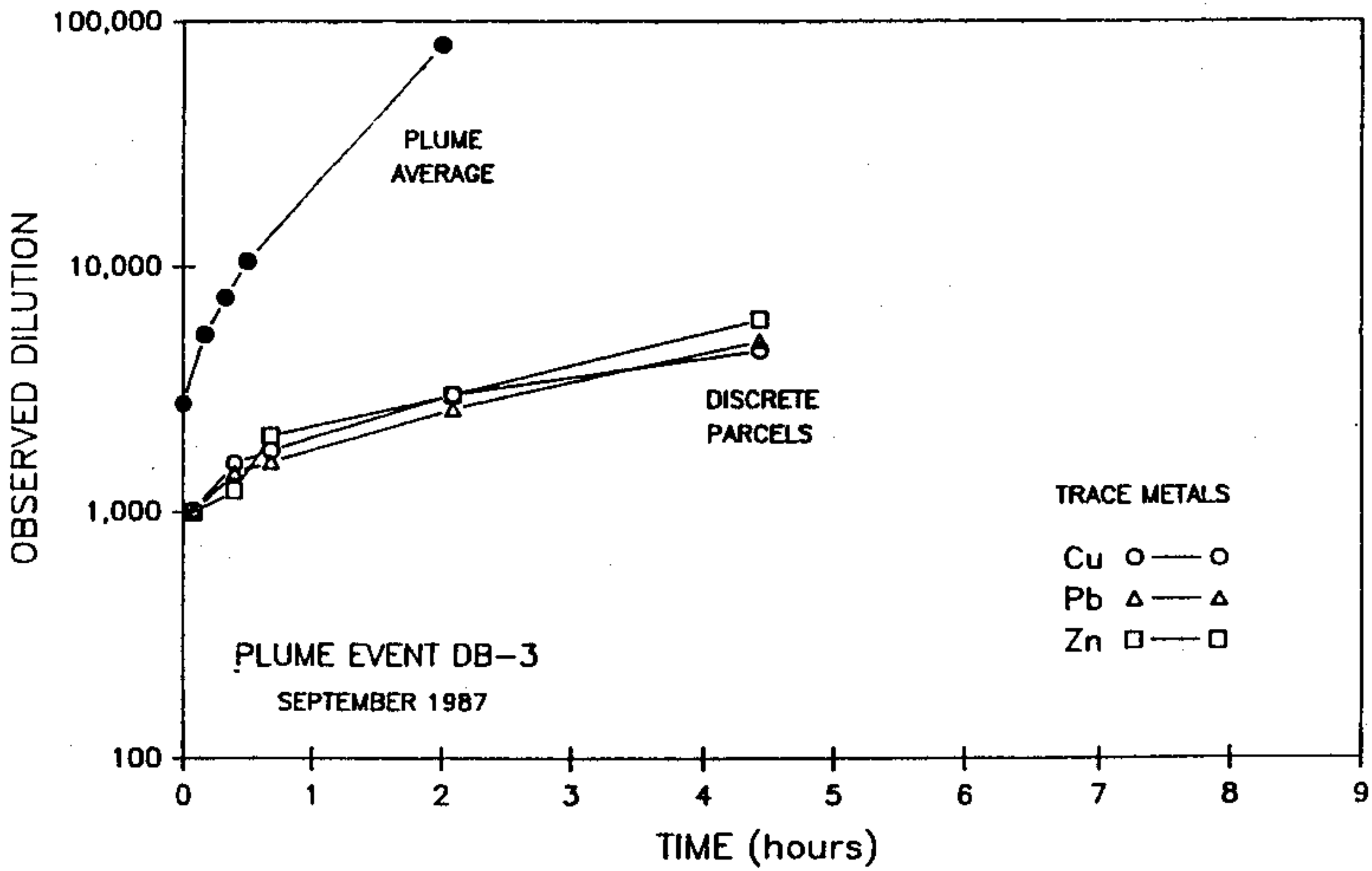


FIGURE 4-10. TIME HISTORY OF SLUDGE DILUTION FOR PLUME EVENT DB-3 DURING SEPTEMBER 1987. SOLID SYMBOLS REPRESENT AVERAGE DILUTION OF ENTIRE PLUME; OPEN SYMBOLS REPRESENT TRACE METALS RESULTS FROM DISCRETE WATER PARCELS WITHIN THE CORE OF THE PLUME.

2. Estimation of dilution as a function of time for the most concentrated portion of the plume.

The results from these individual steps are presented below. The only major assumption inherent in these analyses is that a subset of the transmissometry profiles (either vertical or horizontal) from each plume event intersected the most concentrated portion of the plume. These "core" profiles were easily identifiable due to the high concentrations of turbidity (beam attenuation) relative to background levels.

Identification of the Plume Core

Although turbidity readings were obtained at 30-cm vertical intervals within the plumes during vertical profiling, the highest value of turbidity did not provide a statistical representation of the sludge concentrations within the core of a plume. To better resolve the distribution of sludge (turbidity) concentrations, vertical and horizontal profiles of beam attenuation were analyzed to obtain the percent frequency of occurrence of beam attenuation within specific bins of beam attenuation that range from the highest concentration within the plume to the relatively low values found in the receiving water. After each profile was edited to retain only those measurements from within the plume, the objective sorting analysis yielded results that were independent of (1) the location of the plume within the water column, (2) the vertical and horizontal scales of the plume, and (3) the sampling resolution and direction (vertical or horizontal) of the profile.

Figure 4-11 presents a composite of concentration distributions for four vertical profiles acquired during plume event DB-13 in March 1988. For each profile, the percent frequency of occurrence of 1-s beam attenuation values is indicated for the range of beam attenuation values observed. For profile 3 made 0.33 h after dumping, the maximum beam attenuation exceeded 34 m^{-1}, and the most common reading was 26.8 m^{-1}. For the subsequent profiles during this 2-h sampling period, there was a clear progression toward lower beam attenuation values versus time since dumping. The maximum beam attenuation value for profile 16, which was made 2 h after dumping, was 19 m^{-1}, and the most common value was 1.4 m^{-1}. The relatively high percent

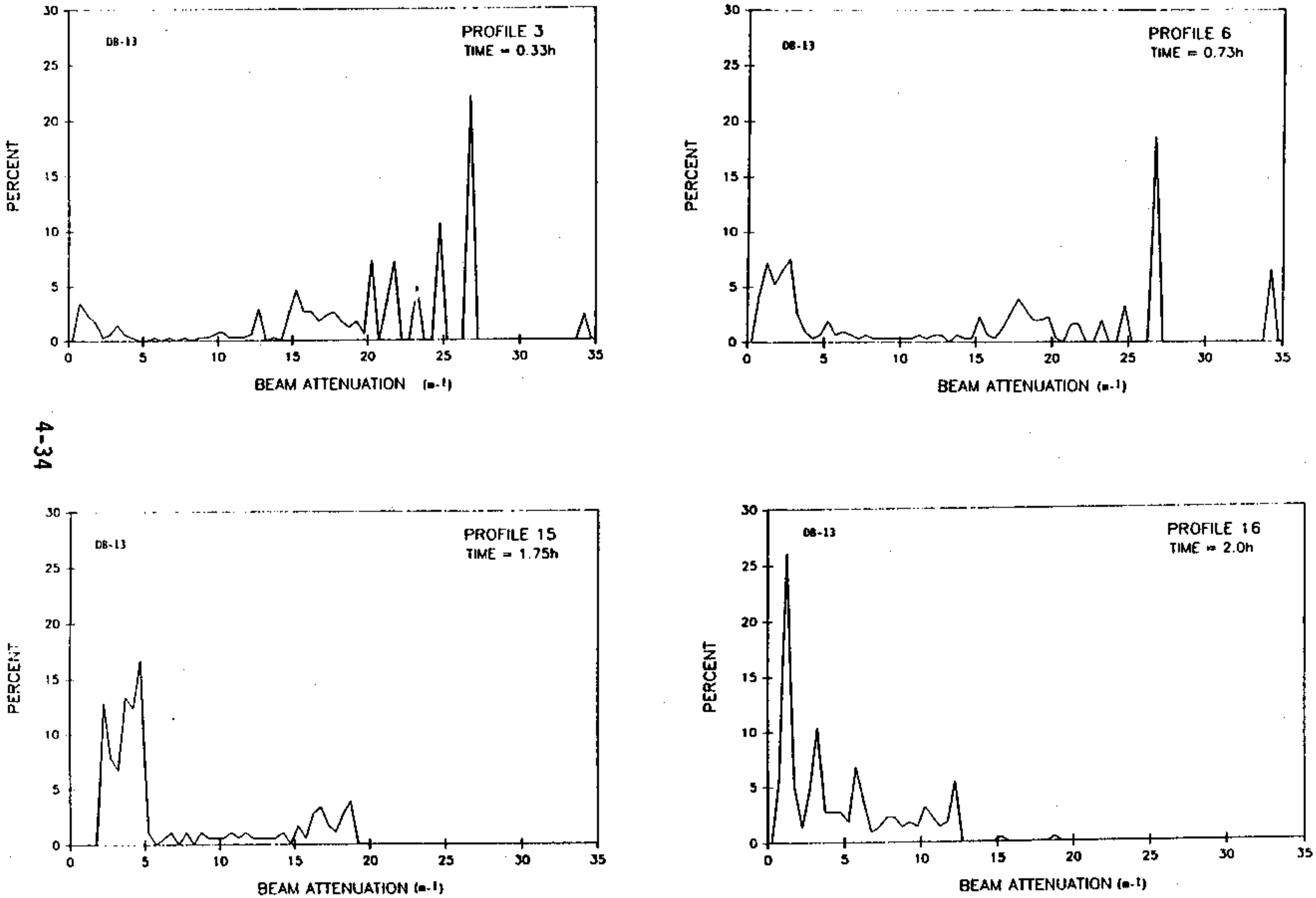


FIGURE 4-11. COMPOSITE OF TURBIDITY (BEAN ATTENUATION) ANALYSES FOR INDIVIDUAL VERTICAL PROFILES OF PLUME EVENT DB-13 IN MARCH 1988. DATA ILLUSTRATE PERCENT FREQUENCY OF OCCURRENCE WITHIN BINS OF BEAM ATTENUATION.

of occurrence (26%) of low turbidity readings illustrates that the plume had not only become more dilute, but had become more homogenized.

For comparison with the results from plume event DB-13 acquired during the survey, Figure 4-12 presents a similar analysis of beam attenuation values within plume DB-3 surveyed in September 1987. Both surveys included vertical profiling within plumes dumped by the Morris Berman; however, the origin of the sludge differed for the two events as discussed in Section 4.3. The results from the two surveys are quite similar: maximum beam attenuations decreased, the value of the most common beam attenuation reading decreased, and plumes became more homogenized with time after dumping. This short-term behavior of sludge plumes was also determined from similar analyses of horizontal profile data from other plumes surveyed during September 1987 and March 1988.

Parcel analysis for each profile (either vertical or horizontal) was also used to quantify, on a volumetric basis, the concentration of the most concentrated portion of a plume. The plume core was defined by a 10 percent threshold (above which 10 percent of the plume measurements lay). This value was chosen arbitrarily, but it may be a reasonable and objective criterion for characterization of the densest part of a plume. The temporal behavior of this plume core was compared with the maximum and median beam attenuation values of the profile.

Figure 4-13 presents time series plots of (1) the 10-percent value (plume core), and (2) the median value of beam attenuation as derived from the analyses of individual profiles described above. In the upper frame, results from plume event DB-13 of March 1988 are presented versus time for the first 2 h following dumping. This figure illustrates that both the plume core and the median value of beam attenuation decreased sharply during this time period. The fact that the plume core results were less consistent (linear) than the median results is most likely related to the difficulty in sampling the densest part of the plume using vertical profiling techniques.

The middle frame in Figure 4-13 presents the results from plume event DB-3 of September 1987. This figure illustrates that shortly after dumping, both the plume core value and the median value of beam attenuation were near 5.1 m^{-1}. With increased time after dumping, both values decreased but the instantaneous difference between the two quantities was much less than that

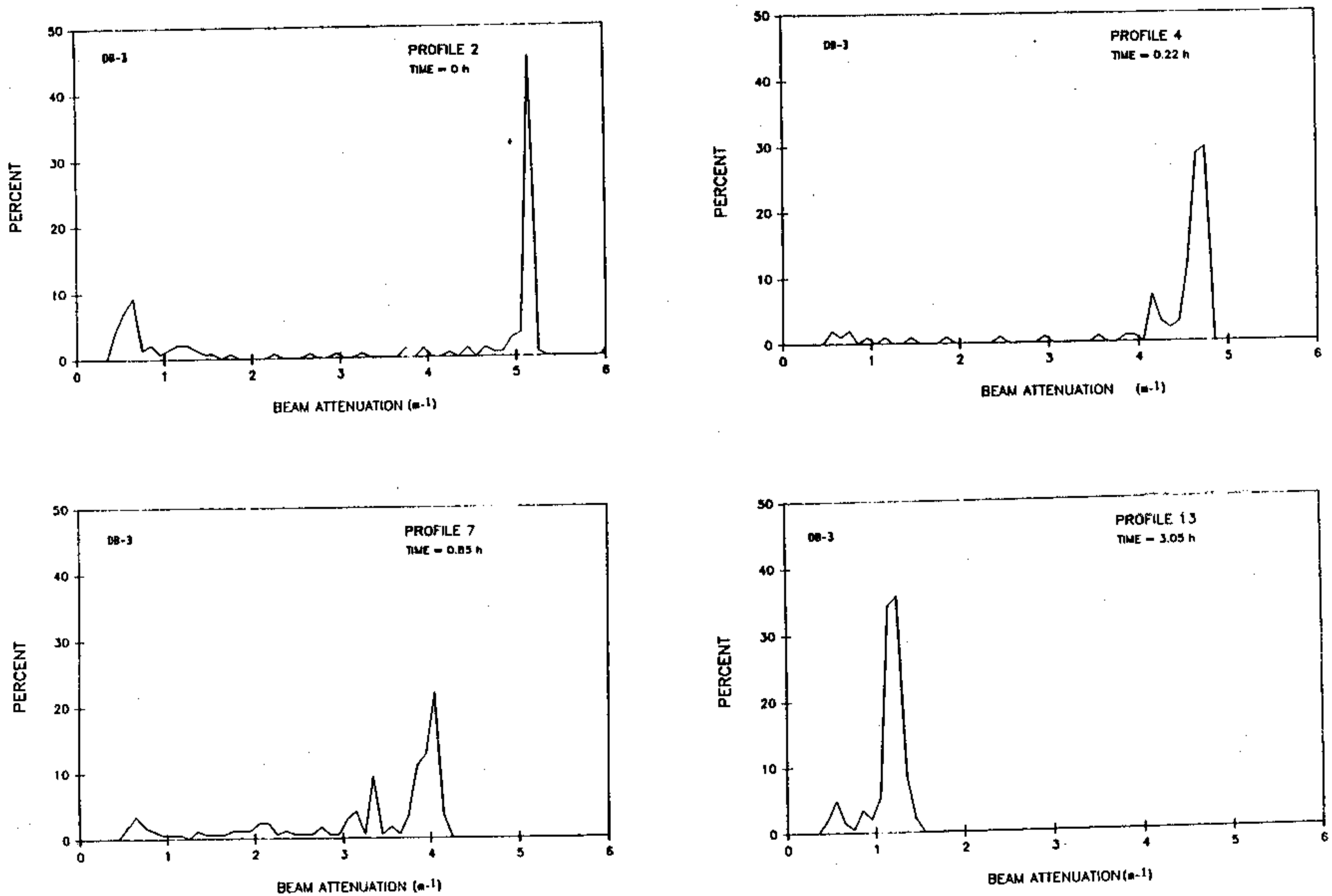


FIGURE 4-12. COMPOSITE OF TURBIDITY (BEAM ATTENUATION) ANALYSES FOR INDIVIDUAL VERTICAL PROFILES OF PLUME EVENT DB-3 IN SEPTEMBER 1987. DATA ILLUSTRATE PERCENT FREQUENCY OF OCCURRENCE WITHIN BINS OF BEAM ATTENUATION.

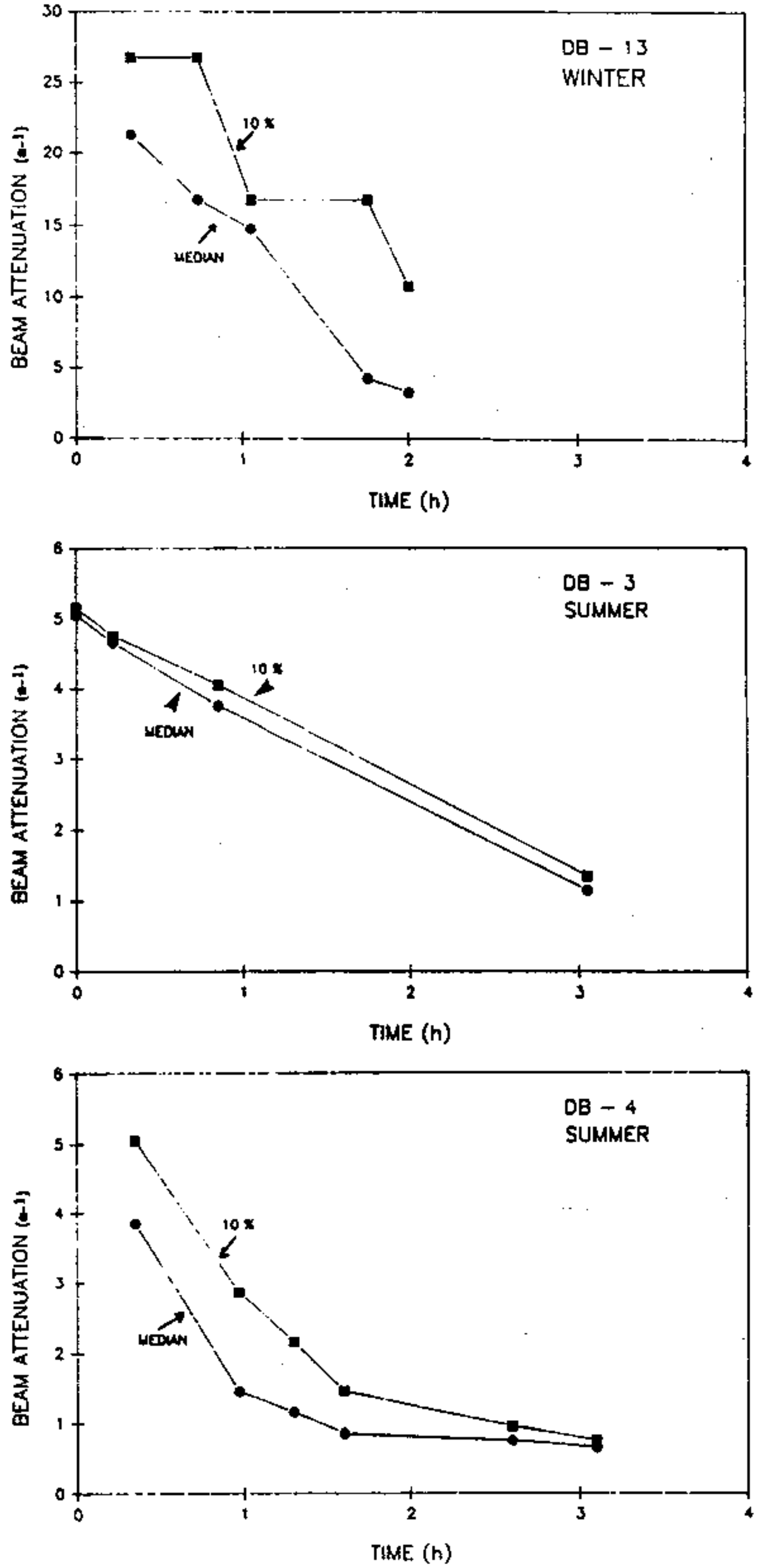


FIGURE 4-13. COMPOSITE OF TURBIDITY (BEAM ATTENUATION) ANALYSES WITHIN THE CORE OF THE PLUME FOR EVENTS DB-13 (UPPER), DB-4 (MIDDLE), AND DB-4 (LOWER). DATA ARE PRESENTED FOR THE MEDIAN TURBIDITY AND THE VALUE REPRESENTING THE MOST CONCENTRATED 10% OF THE PLUME.

observed during plume event DB-13 in March 1988. The higher variability of beam attenuation values within the core of plume DB-13 may have been due to the high turbidity of the Passaic Valley sludge (≈15 m^{-1} at 1 h) compared to the relatively low turbidity of the Port Richmond sludge (≈4 m^{-1} at 1 h) from plume DB-3.

The lower frame of Figure 4-13 presents the results from plume event DB-4 of September 1987. This figure illustrates that both the plume core value and the median value of beam attenuation within plume DB-4 decreased rapidly during the first 2 h after dumping; from 2 h the rate of decrease (dilution) was less.

Plume DB-4 was surveyed using horizontal profiling, whereas plumes events DB-3 and DB-13 were surveyed using vertical profiling. From the results of plume DB-4, it appeared that horizontal profiling may be the best technique for monitoring the short-term behavior of sludge-plume cores. For instance, the lower frame of Figure 4-13 illustrates a gradual, monotonic progression to lower values of beam attenuation for both the plume core value and the median value of the plume. During the first hour after dumping, median values decrease more rapidly than the plume core values, suggesting that the core of the plume was being diluted more slowly than the average for the entire plume. Beyond 1 h, the densest part of the plume was diluted more rapidly than the average plume such that at 3 h, the plume was nearly homogeneous and the concentrated core was practically gone.

<u>Estimation of Dilution within the Plume Core</u>

The previous discussion presented a method for quantifying the turbidity characteristics and temporal behavior of the most concentrated parcels of sludge within sludge plumes monitored at the 106-Mile Site. Hence, this analysis of turbidity data within the core of the plumes is analogous to analyses of TSS and trace metals data from discrete water samples within the core of the plume. As illustrated in Figure 4-10, the trace metal data from plume DB-3 in September 1987 indicated that, after the initial (5 min) period of wake-induced mixing, the rate of dilution within the core of the plume was roughly 1,000:1 per hour for the first 4 h after dumping. Although there were uncertainties in the concentrations of metals within the undiluted sludge from this and other barges surveyed in September, the results from the individual plume events suggest that a dilution rate of 1,000:1 per hour may be representative of short-term sludge plume behavior during summer months.

Using (1) the results of the turbidity analyses for the September 1987 and March 1988 plume surveys (Figure 4-13), (2) transmissometer calibration information for conversion from beam attenuation readings to total suspended solids (TSS) concentrations, and (3) estimates of the TSS concentration of the individual (pure) sludges from Santoro and Fikslin (1987), rates of dilution for the core of the plumes can be determined from the transmissometry data. Table 4-6 presents rate-of-dilution estimates for plumes DB-13 (this survey) and DB-3 and DB-4 (previous summer); rates are given for the plume core (most concentrated 10% by volume) and the plume average (based upon median turbidity values). The results from the plume core indicate that rates of dilution during the first 2 h following dumping were between 2,500:1 and 5,000:1 per hour, which are quite similar to the rate of dilution (1,000:1 per hour) that was determined from the results of trace metal analyses within plume DB-3. Rates of dilution within the core of the plumes became higher as time from T=0 h increased (e.g., 28,735:1 per hour for plume DB-4 from 1.5 to 3.0 h after dumping). Rates of dilution were also much higher for analyses based upon the median TSS concentration within the plumes, rather than concentrations within the core. This analysis indicated that

- Transmissometry data from the core of plumes can be used to estimate rates of dilution; the results are in agreement with results from analyses of trace metals concentrations within water samples.
- During the first 2 h after dumping, the core of a plume dilutes at a rate that is significantly less than the rate for the average plume.
- The rate of dilution within the core of a plume increased with time after dumping; this is presumably a result of erosion (dilution) of the plume from its outer boundaries and a reduction in volume of the core.

TABLE 4-6. SUMMARY OF PLUME DILUTION RATES BASED UPON TRANSMISSOMETRY DATA FROM PROFILING SURVEYS IN MARCH 1988 (DB-13) AND SEPTEMBER 1987 (DB-3 AND DB-4).

Plume Event	Date	Time After Dumping (h)	Rate of Dilution (per hour) Upper 10% (plume core)	Median
DB-13	3/88	0.5-2.0	2,850:1	11,520:1
DB-3	9/87	0.0-3.0	2,600:1	3,790:1
DB-4	9/87	0.0-1.5	4,780:1	20,440:1
"	"	1.5-3.0	28,735:1	191,870:1

Analyses of dilution rates from transmissometry data would be greatly improved with (1) accurate measurements of TSS concentrations within the sludges surveyed and (2) laboratory calibration of the transmissometers using samples of the various sludges.

4.4.2.2 Estimation of Dilution Based on Chemical Tracer Data

Data on metals from sludge plumes surveyed were compared to sludge contaminant data to calculate sludge dilution at the site. The summer 1987 survey showed that sludge dilution consisted of an initial turbulent dilution occurring in the barge wake, and a slower continuing dilution resulting from settling and dispersive oceanic processes (EPA , 1992c). The data from this survey were not as extensive as those from the previous survey, but generally showed the same pattern of sludge dilution.

Dilution estimates calculated from sludge tracers require information on the initial concentrations of tracers in sludge. However, because sludge was not collected from barges dumping at the site, historical sludge contaminant data (Santoro and Fikslin, 1987) were used for calculation of dilution. Use of this historical contaminant data introduces an unknown level of uncertainty in the calculated dilution estimates because actual contaminant levels in the sludges studied probably differ from average historical levels. However, without a historical sludge contaminant data set, dilution calculations could not be made for this survey.

Although data on metals from five plumes were obtained, initial turbulent dilution could only be calculated for two of the plumes because of uncertainties in the sludges contained in two of the barges. The NYCDEP facility at Wards Island combines sludges from several plants in barges for disposal at sea. Because the plants contributing to the two barges originating from Wards Island could not be identified, historical data could not be assigned with any confidence. Therefore, sludge dilution from dumping events DB-10 and DB-14 could not be determined. Tracer samples from DB-11 were clearly not collected in the particle maximum (core) of the plume, and dilution calculations were not made from this plume.

For those plumes with identified sludge sources, of initial sludge dilution was estimated from chemical tracer data (Table 4-7). Estimates

TABLE 4-7. ESTIMATES OF INITIAL DILUTION FOR SEWAGE SLUDGE PLUMES STUDIED IN MARCH 1988. RESULTS BASED ON OBSERVED METAL CONCENTRATIONS IN THE PLUME AT T=0 h AND DATA FROM SANTORO AND FIKSLIN (1987).

Plume	POTW	Metal	Concentration: Sludge (mg/L)	Concentration: T=0 h (µg/L)	Sludge Plume Initial Dilution
DB-10[a]	Wards Island	Cu	NA	19.5	--
		Pb	NA	14.1	--
		Zn	NA	17.2	--
DB-11[b]	Middlesex County	Cu	128	0.40	--
		Pb	64	0.40	--
		Zn	352	1.5	--
DB-12[c]	Passaic Valley	--	--	--	--
DB-13[d]	Passaic Valley	Cu	115	7.5	15,300:1
		Pb	318	34.5	9,200:1
		Zn	137	35.7	3,800:1
DB-14[a]	Wards Island	Cu	NA	12.4	--
		Pb	NA	9.7	--
		Zn	NA	28.8	--
DB-15	Nassau County	Cu	7.4	4.9	1,500:1
		Pb	2.4	2.1	1,140:1
		Zn	12.1	6.4	1,890:1

[a]Origin of sludge unknown. Cannot calculate initial dilution.

[b]Samples were not collected from the particle maximum in the plume; dilution estimates not feasible.

[c]Plume not sampled for tracer parameters.

[d]Initial samples at T=0.3 h were not collected from the plume core.

range from an initial 1,140:1 dilution for DB-15 to a 15,300:1 dilution for DB-13. Estimated dilutions for individual plumes varied according to metal, most likely indicating that actual sludge contaminant concentrations differed from historical data. Generally, the range of estimated initial dilution calculated from the March 1988 data was similar to that calculated from the September 1987 data.

Table 4-8 presents estimates of continuing short-term dilution (after initial turbulent dilution), and estimates of overall rate of sludge dilution with time. Calculations of overall sludge dilution agree with results found in September 1987, and indicated that relatively little additional short-term sludge dilution (less than 10-fold dilution per hour) occurred at the site after initial barge-induced dilution.

The overall dilution calculated for DB-13 from chemical tracer data ranged from 5,500:1 to 14,400:1 per h, depending on the metal used to calculate dilution. These dilution rates were up to 5 times those calculated from light transmission data in the plume core (Table 4-6), but were similar to median dilutions calculated from the same light transmission data. This comparison provided an excellent check on the data. The difference in the two calculations indicates that (1) samples for chemical tracer analysis were not collected in the plume core, (2) historical sludge contaminant data did not reflect actual sludge levels, or (3) partitioning of contaminants from particles to dissolved phase (Section 4.6) may have resulted in higher contaminant levels than was reflected in the particulate loading.

Calculations of sludge dilution from chemical tracer data provide estimates of initial and continuing sludge dilution at the site that were similar to those calculated from light transmission data. The uncertainty of chemical tracer data, both in the plume (because of uncertainty in sample collection) and in the sludge (because historical data were used instead of determining true values) results in uncertainty in the dilution calculations from these data. Turbidity measurements inherently have lower uncertainty associated with the data than chemical measurements because of the high frequency of sampling and the relative simplicity of the measurement. However, because of uncertainties in the physical behavior of sludge particles in the marine environment (flocculation, dissolution), there is

TABLE 4-8. ESTIMATES OF DILUTION AFTER T=0 h FOR SEWAGE SLUDGE PLUMES STUDIED IN MARCH 1988.

Plume	Metal	Concentration (µg/L) T=0 h	Concentration (µg/L) T=x h	Time of Sampling (T=x h)	Additional Dilution[a]	Overall Rate of Dilution[b] (per hour)
DB10[c]	Cu	19.51	1.57	4.3	12:1	--
	Pb	10.6	1.04	4.3	10:1	--
	Zn	17.2	1.41	4.3	12:1	--
	Fe	191	14.0	4.3	14:1	--
DB11[d]	Cu	0.40	NA	-	-	--
	Pb	0.40	NA	-	-	--
DB12[e]		-	-	-	-	--
DB13	Cu	7.5	2.9	1.3	3:1	14,400:1
	Pb	34.5	13.5	1.3	3:1	11,000:1
	Zn	35.7	12.5	1.3	3:1	5,500:1
	Fe	117.1	39.4	1.3	3:1	--
DB14[c]	Cu	12.4	0.43	1.0	29:1	--
	Pb	9.7	0.27	1.0	36:1	--
	Zn	19.5	1.44	1.0	13:1	--
	Fe	154.2	3.21	1.0	48:1	--
DB15[f]	Cu	4.9	1.33	0.5	4:1	8,100:1
	Pb	2.4	0.15	0.5	16:1	30,000:1
	Cu	6.35	2.82	0.5	2:1	4,800:1
	Fe	50.6	1.36	0.5	37:1	--

[a]Dilution after T=0 h; calculated as follows:
Concentration at T=0 h divided by concentration at T=x h.

[b](Concentration at T=0 h divided by concentration at T=x h)/Time of sampling (x).

[c]Origin of sludge unknown. Cannot calculate overall dilution.

[d]No tracer samples collected at T=0 h.

[e]No tracer samples from this plume.

[f]Samples were not collected for the particle maximum in the plume for last samples collected. Therefore, the dilution estimates are overestimates.

also a large uncertainty associated with calculation of sludge dilution from turbidity. Therefore, both measurements complement each other and are necessary for the determination of sludge dilution.

For reasons discussed previously, chemical tracer data from the survey could not be used satisfactorily to calculate sludge dilution. As a result, the determination of sludge dilution under winter conditions requires further study in future surveys.

4.4.2.3 Plume Transport

Knowledge of the time required for sludge plumes to leave the 106-Mile Site is of critical concern because water quality criteria must not be exceeded at any time outside the site. In addition to direct measurements of currents (XCP and drifter data), continual contact with the sludge plumes during the various sampling events (DB-10 through DB-15) of the March 1988 survey provides another estimate of the rates at which plumes are being advected. Table 4-9 summarizes the speed and direction of sludge plume transport for five of the six plume events surveyed during March 1988. No data are provided for event DB-12 because the dumping occurred outside of the site.

Table 4-9 indicates that the surface plumes moved to the north-northeast, with the exception of plume DB-11, which moved toward the northwest. Average transport speeds varied from 2 to 31 cm/s over the 2 days of the survey. Using the average speed and direction of plume transport, the time that would be required for each plume to cross the site boundary was calculated directly As indicated in Table 4-9, these times ranged from 5 to 57 h, assuming that the currents would remain constant over the individual time periods for each plume event. These times were based upon the transport of the specific portion of the plume surveyed, rather than the part of the plume that lies closest to the downstream site boundary. Nevertheless, this analysis suggests that the five plumes did not cross the boundaries of the 106-Mile Site within 4 h after dumping. The slow transport resulted from near-surface current conditions that were much less intense than (1) currents observed during the nearfield survey in September 1987, and (2) currents during the passage of warm-core eddies of Gulf Stream origin, which

TABLE 4-9. SUMMARY OF PLUME TRANSPORT INFORMATION FOR PLUMES MONITORED DURING THE MARCH 1988 SURVEY AT THE 106-MILE SITE.

Event	Date	Start Time	Transport Direction	Transport Speed (cm/s)	Time to Cross Boundary (h)
DB-10	3/2	1212	17°	7	14
DB-11	3/2	2011	339°	2	5
DB-13	3/3	2006	34°	31	5
DB-14	3/4	0719	38°	15	9
DB-15	3/4	1102	28°	6	57

are not uncommon at the site. Under these two conditions, plumes may be advected out of the site within a few hours after dumping. During weak flow condition, which may occur 60 to 80 percent of the time, dumping on the leeward side of the site would ensure that plumes do not cross the site boundaries within 4 h of dumping.

4.5 WATER QUALITY MEASUREMENTS

Two concerns of the 106-Mile Site monitoring program are to verify (1) that the adverse impacts of sludge dumping on water quality at the site, as measured by increased metal and organic contaminant concentrations, and increased pathogen counts, are not in excess of those permitted by the ocean dumping regulations and permit requirements; and (2) that sludge dumping has no significant effect on dissolved oxygen levels at the site. The survey addressed water quality issues through the analysis of water samples collected in sludge plumes for contaminants for which there are water quality criteria. Samples for measurement of these contaminants were collected in five plumes at T=0 h. However, only one plume was sampled for water quality parameters 4 h after disposal. Samples at 4 h could not be collected for other plumes because surveying operations were terminated earlier due to the small plume size or equipment difficulties. Contaminant concentrations have also been calculated from transmissometry data for one plume. Monitoring of dissolved oxygen was conducted with the Seabird CTD. All water quality data are presented in Appendix C.

4.5.1 Comparison to Water Quality Criteria

Analysis of samples collected within the sludge plumes at T=0 h indicated that copper, lead, and mercury exceeded water quality criteria immediately after discharge from the barge (Table 4-10). Copper exceeded the criterion at T=0 h in all plumes except one; the lead criterion was exceeded in three of the five plumes; and the mercury criterion was exceeded in two of the five plumes. Pesticide/PCB concentrations were below water quality criteria in all samples monitored. Samples collected within the plumes at least 1 h after disposal suggested that all metal contaminants were

TABLE 4-10. COMPARISON OF METAL MEASUREMENTS IN SLUDGE PLUMES DB-2 AND DB-3 APPROXIMATELY 4 h AFTER DISPOSAL AT THE 106-MILE SITE TO EPA MARINE WATER QUALITY CRITERIA.

Plume	Sample Depth (m)	Rep	Time After T0 (h)	As	Ag	Cd[a]	Cu	Cr	Fe[a]	Ni	Pb	Se	Zn[a]	Hg
				µg/L										ng/L
DB10	1	2	0.1	1.410	0.149	0.323	19.51	9.09	190.86	2.395	14.09	<0.036	17.23	9.1
DB10	4.5	1	4.3	1.314	0.053[b]	0.041[b]	1.56[b]	0.63	13.95[b]	0.435[b]	1.04[b]	<0.038[b]	1.41[c]	6.6
DB11	2.5	2	0	0.824	0.0083[b]	0.034	0.40	0.29	2.97	0.336	0.38	<0.038	1.51	4.7
DB13	1	1	0.3	1.287	0.096	0.502	7.48	11.14	117.05	1.677	34.46	<0.052	35.73	88.3
DB13	3	1	1.6				2.90		39.35		13.53		12.46	
DB14	2	1	0	2.033	0.144	0.133	12.43	2.48	154.22	1.137	9.66	<0.039	19.48	29.8
DB14	4	1	1				0.43		3.21		0.27		1.44	
DB15	1	1	0	1.896	0.107	0.056	4.86	0.47	50.59	0.884	2.13	<0.038	6.35	10.2
DB15	2.5	1	0.5				0.296		1.36		0.09		1.38	
Water Quality Criteria				36	2.3	9.3	2.9	50	NA	8.3	5.6	54	86	25

[a] Blank corrected.
[b] Mean of replicate analysis.
[c] Duplicate rejected due to suspected contamination.

at or below water quality criteria, with the exception of lead in DB-13, which exceeded the water quality criteria 1.6 h following disposal.

However, for at least one plume (DB-13), it can be verified that sampling for water quality measurements did not occur in the plume core. Based on transmissometry observations, the core of plume DB-13 was dispersing at a rate of 2,850/h (Table 4-6). Given this dispersion rate, the plume would have been diluted 11,400-fold after 4 h. At this dilution, copper and lead would be present at 10 µg/L and 28 µg/L, respectively; both above water quality criteria.

This analysis of water quality parameters from turbidity measurements provides an independent check on the chemical measurements made on actual samples. Comparison of analytical results to water quality criteria are predicated on the assumption that the volume of maximum contaminant concentrations within the plume was always sampled. As with plume DB-13, this did not always occur. Sampling in the sludge core might have revealed higher concentrations of contaminants that may have exceeded water quality criteria.

4.5.2 Clostridium perfringens

A microbiological tracer of sewage sludge, C. perfringens, was found at elevated levels in all sludge plumes sampled except DB-13 (Table 4-11). Compared to the September 1987 survey, fewer samples had C. perfringens levels that were too numerous to count, indicating that shipboard processing modifications provided more reliable data than obtained in the summer 1987 survey. As found during the summer 1987 survey, C. perfringens concentrations in sludge varied substantially among the various authorities disposing sludge at the 106-Mile Site. No measurable C. perfringens spores were found in sludge plume DB-13; sludge originating from Passaic Valley. Passaic Valley uses the Zimpro method of employing high temperature and pressure for sludge dewatering. This treatment presumably was effective in killing all C. perfringens spores in the Passaic Valley sludge. Complete C. perfringens data are presented in Tables C-2 in Appendix C.

TABLE 4-11. CONCENTRATIONS OF *C. perfringens* IN THE SLUDGE PLUMES AT T=0 h AND BETWEEN 0.5 AND 4 h AFTER DISPOSAL. (RESULTS ARE BASED ON THE MAXIMUM OBSERVED IN THE SET OF REPLICATE SAMPLES FOR THE SAMPLE PERIOD.)

Plume	T=0 h	T=x h	x (h)
DB-10	420	34	4.3
DB-11	3.5	NA	-
DB-13	0	0	1.6
DB-14	TNTC	62	1.0
DB-15	964	52	0.5

TNTC = Colonies too numerous to count.

NA = Not available.

4.5.3 Dissolved Oxygen

Using the same methods employed during the previous survey, dissolved oxygen concentrations were monitored continuously during vertical and horizontal profiling operations using an in situ oxygen probe interfaced to the CTD/transmissometer profiling system. Results of these analyses agreed with those of the September 1987 survey revealing that perturbations in dissolved oxygen levels were at or below the resolution of the oxygen probe (ca 0.1 ml/L) and that levels of dissolved oxygen in site waters were essentially unaffected by sludge dumping. Because the effect of sludge dumping on dissolved oxygen levels was so small, further analyses of oxygen data were not made. Further characterization of dissolved oxygen at the site would require that in situ profiling be supported with multiple oxygen titration analyses, an effort that does not appear warranted based on data from this survey and the previous survey.

4.6 DISSOLVED AND PARTICULATE CONTAMINANT DISTRIBUTION

Prediction of the long-term fate of sludge contaminants at the 106-Mile Site requires an understanding of how the sludge contaminants partition between dissolved and particulate phases after disposal. Nearfield monitoring strategies are based on the assumption that sludge contamination follows the particulate phase. However, sludge components found primarily in the dissolved phase at the time of disposal or redistributing from the particulate phase to the dissolved phase after disposal will not settle with the particulate matter and thus may be transported from the disposal site by different routes and at different rates than those components remaining in the particulate phase. Therefore, depending on the rate of contaminant redistribution, the current strategy of fate monitoring based on transmissometry may not give a true account in the nearfield and may not be completely effective in the farfield.

To examine the question of sludge partitioning after disposal, samples for analysis of total and particulate metals were collected from the sludge plumes as a function of time. The comparison of concentrations of metals in both phases allows an assessment of sludge contaminant redistribution after disposal, information that is needed for resolving the issue of contaminant redistribution. Only a limited number of samples and a limited number of elements were analyzed for this preliminary study to determine if redistribution occurred at the site. Cadmium, copper, iron, lead, nickel, and zinc were analyzed in dissolved and particulate samples at T=0 h, whereas only copper, iron, lead, and zinc were analyzed in samples collected later during each event.

Because of the high particulate concentrations, most of the toxic compounds and metals in the sewage sludge dumped at the 106-Mile Site were initially associated with the solid (particulate) phase (Table 4-12). Analysis of metal contaminants in the dissolved and particulate phases of sludge plumes at the 106-Mile Site revealed the following regarding the behavior of this metal contamination:

- At T=0 h, the relative amount of particulate to dissolved metal was similar to, but somewhat lower than, that of the original sludge values. The exceptions were nickel and copper, which appeared to partition from the particulates immediately upon disposal (Table 4-12).
- For all but one dumping event (DB-13), data for metals indicated a selective partitioning of metal contaminants from the particulate to the dissolved phase in the short term (Table 4-13). Partitioning was element-specific, with iron showing the least partitioning of the elements analyzed.
- Anomalous behavior of sludge from Passaic Valley (dumping event DB-13) may be related to post-digestion high temperature and pressure dewatering treatment (Zimpro process).

The apparent decrease in the fraction of the total metal associated with the sludge particles after disposal implied that at least some metal contamination moves from the particulate phase to the dissolved phase when sludge is disposed in the ocean, most likely as a result of desorption of metals from sludge particles. However, the percentage of the metal originally associated with the sludge particles that is transferred to the dissolved phase after disposal could not be determined because undiluted sludge was not characterized in this study. The time scale of this repartitioning appeared to be rapid, on the order of minutes to hours.

TABLE 4-12. COMPARISON OF PARTITIONING OF METALS BETWEEN DISSOLVED AND PARTICULATE PHASES IN SLUDGE DUMPED AT THE 106-MILE SITE. UNITS ARE IN PERCENT OF THE ELEMENT IN THE PARTICULATE PHASE.

Metal	Sludge[a]	Plume at T=0 h					Background
		DB-10	DB-11	DB-13	DB-14	DB-15	
Cd	97-99.5	85	NA	100	57	86	≈25
Cu	90-99	83	43	100	52-81	42-91	6-10
Fe	NA	65-77	100	100	54-74	49-87	44-100
Pb	95-99.8	73-90	64-74	100	55-75	>80	2-60
Ni	80-95	43-70	NA	70	21-28	14-23	0-13
Zn	92-98	96	100	100	64-113	79-100	NA

[a]Based on results included in the permit applications from the 9 sewerage authorities applying for permits to dispose sludge at the 106-Mile Site.

TABLE 4-13. PARTITIONING OF METALS BETWEEN DISSOLVED AND PARTICULATE PHASES IN SLUDGE DUMPED AT THE 106-MILE SITE AT T_0 AND AT LEAST 1 h AFTER DISPOSAL. UNITS ARE IN PERCENT OF THE ELEMENT IN THE PARTICULATE PHASE.

	DB-10		DB-13		DB-14		DB-15	
Metal	T=0 h	T=4.3 h	T=0 h	T=1.6 h	T=0 h	T=1 h	T=0 h	T=0.5 h
Cu	83	66	100	100	52-81	29	42-91	33
Fe	65-77	55	100	100	54-74	73-93	49-87	89-100
Pb	73-90	66	100	97	55-75	27-44	>80	33-56
Zn	96	100	100	100	64-100	29-67	79-100	18-32

The dissolution of particulate metals (and presumably other particulate contamination) has several implications on the short- and long-term fate of sludge dumped at the site:

- Short-term (0 to 24 h) settling of sludge may remove only a portion of the contaminants from the ocean surface to the region of the pycnocline. Other contamination may remain dissolved in surface water.
- Transport vectors of contaminants on sludge particles may be different than that of contaminants in the dissolved phase because the particulate phases may settle into ocean regions being transported in directions different than the surface waters. This may be particularly important if ocean currents at depth, where the particles will eventually reside, are different from those at the ocean surface. Thus, long-term, farfield fate monitoring programs (e.g., sediment collections) must consider the diverse nature of the transport pathways if detection of sludge components is to be successful.
- Under certain oceanographic conditions of slow current movement and limited turbulence, the nearly continuous sludge disposal at the site (1 to 4 barges per day) may cause a detectable increase in surface water contamination in and adjacent to the site. The residual dissolved signal from the sludge may be decreased only through mixing or relatively slow natural depositional processes. If mixing is relatively slow, dilution will not occur, increasing the likelihood of elevated contaminant concentrations in the site.

The partitioning of contaminants from particulate phase to dissolved phase complicates farfield monitoring at the site. Because many contaminants in a residual sludge plume are likely to be in the dissolved phase, oceanic mixing will be the primary mechanism for decreasing the contaminant concentrations in the surrounding seawater. Removal from the ocean will be slow and by natural biogeochemical processes. Because the natural removal processes are slow relative to the sludge settling, the sludge contaminants in the residual plume may be transported far from the disposal site before they are mineralized and deposited in the ocean sediments. Thus, a farfield fate monitoring program to detect such deposition would be difficult to design. Additionally, a residual plume of dissolved contaminants in the surface ocean would not be detected or measured using transmissomery-based methods of plume tracking. Thus, the transport of dissolved contaminants will be difficult to monitor with current tracking methods. The transmissometer used to detect the particulate phases of the sludge in the nearfield will certainly not detect the dissolved residual phase of the sludge plume in the farfield. Only sophisticated sampling techniques or widespread collection of seawater from numerous and widely dispersed stations could detect the presence of dissolved contamination in the farfield.

4.7 OBSERVATIONS OF CETACEANS AND MARINE TURTLES

A total of 17 cetaceans (5 sightings) representing 3 species were observed between March 1 and 5, 1988. Three sightings of fin whales (*Baleanoptera physalus*) were made north of the site, and an additional sighting was made within the boundaries of the site. Two non-endangered species (pilot whales, *Globicephala melaena*, and bottlenosed dolphins, *Tursiops truncatus*) were also observed throughout the study area. Cetacean densities are presented in the site condition report (EPA , 1988c). There were no sightings of marine turtles during this survey.

5.0 CONCLUSIONS

5.1 DISCUSSION OF NULL HYPOTHESES

Monitoring the nearfield fate of sludge plumes is one component of Tier 2 monitoring activities presented in the 106-Mile Site monitoring plan (EPA , 1992a). Nearfield fate monitoring addresses both permit compliance and impact assessment. It addresses permit compliance because the permits for disposal of sludges at the 106-Mile Site will stipulate that water quality criteria (WQC), where they exist, may not be exceeded within the site 4 h after dumping and outside the site at any time. When WQC do not exist, the permits will require that the waste concentration not exceed a factor of 0.01 of a concentration known to be acutely toxic after initial mixing, i.e., the limiting permissible concentration (LPC). The combined conformance to LPCs and WQC is thought to be protective of the marine environment.

Nearfield fate (and short-term effects) monitoring also addresses the potential for impacts within the immediate vicinity of the site and in the short term, defined for convenience as 24 h. Nearfield fate determinations address the horizontal and vertical behavior and movement of sludge within and immediately adjacent to the site. Monitoring the behavior and movement of sludge immediately after disposal is necessary to confirm assumptions made about dispersion and dilution when issuing permits.

The 106-Mile Site monitoring plan (EPA , 1992a) uses site and waste characteristics to predict possible impacts of sludge disposal and formulate testable null hypotheses that these predictions suggest. Results of the survey are discussed in terms of hypotheses addressing issues associated with Tier 2 of the monitoring plan. Where applicable, results of this survey are compared to those of the previous survey to the 106-Mile Site. The hypotheses $H_0 3$ through $H_0 9$ are divided into two categories: permit compliance and impact assessment.

Permit Compliance: Nearfield Fate

$H_0$3: Concentrations of sludge and sludge constituents outside the site are below the permitted LPC and WQC at all times.

> Because of low surface current drift at the site during the time of the survey, sludge plumes monitored at the site were not observed to cross site boundaries during the March 1988 survey. Analysis of transport suggests that water quality criteria would not be exceeded outside the site for these plumes.
>
> One barge was found dumping outside of site boundaries. Concentrations of sludge and sludge constituents probably exceeded permitted levels for this plume.

$H_0$4: Concentrations of sludge and sludge constituents within the site are below the permitted LPC and WQC 4 h after disposal.

> Concentrations of all sludge contaminants for which there are marine WQC were below or calculated to be below WQC 4 h after disposal, as determined by analysis of water samples in sludge plumes. Dilution rates of plume cores (most concentrated parcels) calculated from transmissometry suggest that had samples been collected in the plume core of DB-13, WQC would have been exceeded for at least copper and lead. Therefore, at least for this plume, samples collected for water quality analyses probably were not representative of the most concentrated volume in the plume and therefore WQC data for this survey may have underestimated contaminant levels at the site.

$H_0$5: Pathogen levels do not exceed ambient levels 4 h after disposal.

> The microbial tracer, _C. perfringens_, exceeded ambient levels in the only sludge plume sampled at T=4 h. _C. perfringens_ is not a pathogen, but a conservative microbial tracer of sewage; therefore, _C. perfringens_ data are not conclusive proof that pathogen levels are being exceeded 4 h after disposal. Measurements of _C. perfringens_ suggested that this hypothesis was false, direct measurements of pathogens will be requried to prove it false.

Impact Assessment: Nearfield Fate

$H_0 6$: Sludge particles do not settle in significant quantities beneath the seasonal pycnocline (50 m) or to the 50-m depth at any time, within the site boundaries or in an area adjacent to the site.

Sludge was observed to penetrate the surface pycnocline (between shelf and slope waters) and descend to 80 m within 3 h after dumping during one dumping event. The deep penetration may have been related to a dumping rate in excess of the court-ordered 15,500 gal/min. Sludge dumped at the court-ordered rate of 15,500 gal/min or less was observed to remain within the upper 25 m during winter oceanographic conditions. This hypothesis was therefore demonstrated to be false under the observed conditions.

$H_0 7$: The concentration of sludge constituents within the site does not exceed the LPC or WQC 4 h after disposal and is not detectable in the site 1 day after disposal.

As stated in $H_0 4$, sampling and analysis of water samples for sludge constituents was insufficient to determine if WQC were exceeded 4 h after disposal.

Some surface water collected for background contaminant analysis contained metal contaminant levels approaching or exceeding WQC. The high levels probably resulted from previous dumping activity at the site, although this cannot be verified from the data. In the absence of surface currents that would remove surface contamination, the frequency of dumping at the site creates the potential for contaminants to accumulate in surface waters.

Although not observed, the rapid formation of two fractions of sludge plumes (one containing dissolved contaminants, the other containing particulate matter) can be predicted from the limited data set on dissolved and particulate contaminants in sludge plumes. A plume of dissolved contaminants would not disperse rapidly under conditions observed at the site, and the predicted presence of such a plume might be the cause of the elevated contaminant levels observed in background samples.

H_o8: The concentration of sludge constituents at the site boundary or in the area adjacent to the site does not exceed the LPC or WQC at any time and is not detectable 1 day after disposal.

No plumes dumped in the site were observed to cross site boundaries within 4 h during the March 1988 survey.

It was estimated that one sludge plume monitored outside the site could have easily been monitored for over 24 h given the high TSS levels and rate of dilution. The high TSS levels were believed due to a dumping rate in excess of the court-ordered maximum. This hypothesis was probably false under the conditions observed during the survey.

H_o9: The disposal of sludge does not cause a significant depletion in the dissolved oxygen content of the water nor a significant change in the pH of the seawater in the area.

The observed depression in dissolved oxygen levels in sludge plumes is minor and at the limit of instrument resolution. During the winter survey, pH was not monitored in sludge plumes.

5.2 EVALUATION OF MEASUREMENT TECHNIQUES

The March 1988 survey was the second field application of proposed technical guidance for plume-tracking activities to be conducted as part of the 106-Mile Site monitoring program, and the first to be conducted under winter conditions. A secondary objective of the survey was to evaluate methods that may be used in the future by EPA or by permittees. The following methods (originally presented in Sections 2.0 and 4.0) are evaluated in terms of the success of the March 1988 survey:

- **Identification and tracking of a sludge plume with dye and surface and subsurface drogues.**

  Both dye and drogues worked well for identifying a portion of a sludge plume for surveying. Dye mixed in from the R/V Endeavor resulted in only a surface expression, and thus could not be used to monitor dispersion. Dye introduced from the barge would be more useful as a sludge tracer.

- **Monitoring the movement and dispersion of the marked sludge plume with visual observations from a survey vessel and a aircraft.**

  All visual observations were successful in monitoring the movement and dispersion of the plume. Aerial photo-reconnaissance proved to be a useful tool for determining the orientation and width of the plume during the first half hour after dumping. However, difficulties in scheduling dumping operations during daylight hours often precluded aerial reconnaissance.

- **Acquisition of in situ transmissometry data to monitor the movement and dispersion of the plume.**

  As with the previous survey, transmissometry was the most sensitive and reliable real-time tracking method and provided the most data for nearfield fate analyses. Horizontal transmissometry profiling (transmissometer on a V-fin depressor) allowed continuous profiling while the ship was underway and making reciprocal passes through the sludge plume.

  Development of data reduction algorithms to isolate and manipulate transmissometry data from the plume (highest 10 percent transmissometry readings) was directed by the requirement of the ocean dumping regulations to observe concentrated parcels of plume water. This data reduction capability has enhanced the value of transmissometry data and was a significant addition to the analyses of the previous survey.

- **Collection of samples for chemical and biological tracers and total suspended solids to determine actual concentrations of sludge components and dilution of these components.**

  Sample collection was limited on the March 1988 survey because (1) sample collection was isolated from profiling activities (discrete sampling vs pumping), and (2) there were technical difficulties with discrete sampling equipment. Because of the limited number of samples and because the sample collection was not mated to turbidity profiling, transmissometry data could not be related to sludge constituents at the site. Therefore, chemical and biological tracer and TSS data were not as valuable as those same data collected on the previous survey.

Future nearfield fate surveys at the site should return to a directed (by transmissometry) pumping system so that chemical and biological tracer data and TSS can be used to calibrate shipboard measurements. Such a directed pumping system would enhance the defensibility of all of the data resulting from the survey.

- **Acquistion of satellite-derived ocean frontal analyses, CTD profiles, and measurements of current shear to determine the oceanographic conditions that may have impacted the data generated during the survey.**

  In addition to providing critical information for post-survey data analysis, the above oceanographic measurements also provided data that were extremely useful at sea for predicting sludge plume behavior. CTD profiles and current shear measurements proved necessary for interpretation of nearfield fate data.

- **Acquisition of real-time navigation data to support plume-tracking activities.**

  Real-time navigation provided critical information necessary for positioning the ship during plume tracking. By showing the position of the ship in relation to the plume, real-time navigation was an indispensible aid to the plume-tracking survey.

6.0 REFERENCES

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APPENDIX A

DATA QUALITY REQUIREMENTS AND OBJECTIVES

A.1 DATA QUALITY REQUIREMENTS AND OBJECTIVES

The data requirements for chemical analysis are summarized in Table 3-2. Accuracy of the chemical results was determined by analysis of procedural blanks, matrix spikes, and certified reference materials, when reference materials were available. Selected samples were also spiked with known amounts of the analyte of interest and the recovery of the spike monitored to determine extraction efficiencies. For organic compounds, both field and laboratory extraction efficiencies were monitored through addition of surrogate compounds. Precision of analysis was determined by analysis of duplicate samples.

The accuracy of *Clostridium perfringens*, particulate trace metal, and total suspended solids (TSS) results could not be evaluated because certified reference standards are not available and spiking samples for these parameters was not feasible.

A.2 QUALITY CONTROL RESULTS

A.2.1 Total Suspended Solids

Analysis of duplicate TSS samples showed high relative percent difference (RPD) that exceeded the quality control objectives for this analysis. The high RPD was probably due to the settling of particles in the Go-Flow bottles prior to removal of the samples. Two field procedural blanks indicated field conditions may have contributed between 0.03 and 16 mg to each TSS determination. Because the field blank was variable, TSS results were not corrected for the blank contribution.

A.2.2 Metals

The method detection limits determined during the analysis of the samples for trace metal concentrations are listed in Table A-1. Except for selenium, the method detection limits were sufficient to quantify the concentration of the metals at background oceanic levels. With one exception, detection limits achieved were within the objectives for this project. Arsenic concentrations at the site were well above the detection limit achieved, allowing this element to be quantified in all samples. Results of procedural blanks (Table A-2) indicate metals were processed and analyzed without significant contribution of contaminants to the sample. A consistent contribution from the analytical procedures was found for cadmium, iron, mercury, and zinc. Sample results were corrected for these blanks. Analysis of sample duplicates indicated excellent precision (<15 percent as the RPD) was obtained in the laboratory (Table A-3). The precision of the chromium (31% as the RPD) analysis was approximately twice that listed in the data requirements objective. Precision estimates for zinc were not obtained due to an anomalous zinc concentration in one of the sample replicates.

Recoveries of matrix spikes (Table A-4) were excellent. The recoveries ranged between 75 and 121 percent of the known addition for most metals. Low recoveries of silver (≈54%) were observed. Iron recoveries were variable. Significant overrecovery was not observed for any metal, indicating contamination-free processing of the samples. Metal recoveries from certified seawater samples (Table A-5) were in the same range observed for the matrix spikes (77 to 131%). Silver, mercury, and selenium were not certified in standard seawater, therefore no estimate of accuracy was available from this quality control check.

Certified reference material is not available for marine particulate matter. Also, collection of a sufficient mass of particulate matter to enable spiking of the particulate samples was not practical. Therefore, accuracy checks on the recovery efficiency of the particulate method are not available. Estimates of precision for duplicate particulate metal samples (Table A-6) ranged between 24 to 166 percent as the RPD (Table A-7). Iron had a higher RPD than any of the other metals. A small and variable amount of contamination from the analytical procedures was observed in procedural blanks for most of the metals. This variability may have caused some of the observed variability in the particulate metal results. However, variability observed in the particulate metal results was more likely due to heterogeneity of the water within the Go-Flow sampling bottle.

A.2 ORGANIC COMPOUNDS

Method detection limits for the pesticides and polychlorinated biphenyl (PCB) analysis are shown in Table A-8. Detection limits achieved were generally 10 times lower than listed in the analytical objectives for this survey. Recoveries of organic compounds were determined at two steps of the extraction procedure, during field extractions and within the laboratory. Field recoveries were determined by the addition of a known amount of decachlorobiphenyl to each sample during sample extraction on the survey vessel. The recoveries determined for this compound were low and variable (Table A-9), ranging between 12 and 53 percent. Sample results were not corrected for this extraction efficiency. In the laboratory, analysis of a blank spike containing a suite of compounds was conducted (Table A-10). Recovery of compounds from the two spiked samples was excellent with the exception of $Cl_2(8)$. The results indicate that the cleanup step (silica-alumina column chromatography) used to remove interfering organic compounds was successful. Replicate analysis of one extract gave excellent precision for those compounds detected in each sample split (Table A-11).

TABLE A-1. METHOD DETECTION LIMITS FOR ANALYSIS OF SAMPLES FOR TRACE METAL CONCENTRATIONS DURING NEARFIELD MONITORING SURVEY MARCH 1988.

Analyte	Detection Limit (µg/L)	
	Whole Water	Particulates[a]
Arsenic	0.062	NA
Cadmium	0.001	0.003
Chromium	0.006	NA
Copper	0.009	0.010
Iron	0.03	0.06
Lead	0.004	0.005
Mercury	0.00003	NA
Nickel	0.05	0.007
Selenium	0.04	NA
Silver	0.002	NA
Zinc	0.004	0.03

NA = Samples not analyzed for these metals.

[a]Based on 500 mL sample volume.

TABLE A-2. RESULTS OF PROCEDURAL BLANKS ANALYZED WITH TRACE METAL SAMPLES, NANOGRAMS OF METAL CONTRIBUTED TO EACH SAMPLE.

Sample	Metal										
Type	Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Whole water samples											
Water	0.35	<.31	<.78	1.05	<1.7	14.4	0.42	<9.4	<.70	<1.6	NA
Quality	0.34	NA	<.68	<.90	<1.7	11.0	0.26	<9.4	<.70	NA	3.78
	0.34	NA	NA	<.90	NA	NA	NA	NA	NA	NA	NA
Tracer	NA	NA	NA	NA	<1.6	26.6	NA	NA	<1.2	NA	8.8
	NA	NA	NA	NA	<1.6	23.0	NA	NA	1.5	NA	11.0
	NA	NA	NA	NA	2.2	38.2	NA	NA	2.4	NA	12.9
Particulate Field Blanks											
	NA	NA	<1.1	NA	<4.7	240	NA	<3.3	12.2	NA	524
	NA	NA	2.8	NA	<4.7	120	NA	6.3	7.7	NA	768

NA = Not available for this sample.

TABLE A-3. PRECISION OF DUPLICATE SAMPLE ANALYSIS PRECISION REPORTED AS THE RELATIVE PERCENT DIFFERENCE (RPD).

Source Plume	Time (h)	(Depth) (m)	Metal Ag[a]	As[a]	Cd	Cr[b]	Cu	Fe	Hg	Ni	Pb	Se	Zn
Whole Water, μg/L													
DB10	4.3	(4.5)	0.0077	0.809	0.044	0.44	1.54	13.87	NA	0.417	1.037	<0.066	17.99
DB10	4.3	(4.5)	0.0090	0.839	0.038	0.32	1.57	14.03	NA	0.453	1.036	<0.069	1.41
MEAN			0.0083	0.824	0.041	0.38	1.56	13.95	-	0.435	1.036	-	-
%RPD			16	4	15	31	2	1	-	8	0	NA	NA
DB13	1	(5)	-	-	-	-	3.23	43.98	-	-	15.34	-	15.08
DB13	1	(5)	-	-	-	-	3.45	39.89	-	-	16.83	-	15.50
mean			-	-	-	-	3.34	41.94	-	-	16.08	-	15.29
%RPD			-	-	-	-	6	10	-	-	9	-	3
Particulates[c], μg/L													
DB10	4.3	(4.5)	-	-	0.021	-	0.88	1.30	-	0.183	0.493	-	1.34
DB10	4.3	(4.5)	-	-	0.028	-	1.17	14.1	-	0.121	0.879	-	1.71
Mean			-	-	0.025	-	1.03	7.69	-	0.152	0.690	-	1.53
%RPD			-	-	28	-	28	17	-	39	56	-	24

[a]Plume DB-11, Replicate 1, 2.5 m, 0 h after disposal.

[b]Plume DB-11, Replicate 2, 2.5 m, 0 h after disposal.

[c]Field duplicate from one sample bottle.

TABLE A-4. RECOVERY OF METALS FROM WATER SAMPLES SPIKED WITH KNOWN AMOUNTS OF METAL. RECOVERIES WERE DETERMINED FOR A SAMPLE COLLECTED IN PLUME DB-10 at T=4.3 h AND 4.5 m DEPTH UNLESS OTHERWISE NOTED. UNITS ARE IN PERCENT RECOVERED.

Sample Type	Metal										
	Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Water Quality	59[a] 51[a] 54[a]	105[a]	106	77	121	100	84[b] 77[b] 75[b] 75[b]	100	101	117	98
Tracer					113[c]	116[c]			110[c]		117[c]

[a]Spike to sample from plume DB11; sample T=0 h, 2.5 m, replicate 2.

[b]Blank spike recoveries.

[c]Spike to sample from DB13, T=1.2 h, 5 m, Replicate 1.

TABLE A-5. RECOVERY OF METALS (PERCENT) FROM STANDARD REFERENCE SEAWATER (CASS-1) ANALYZED WITH EACH BATCH OF EXTRACTED SAMPLES.

Sample Type	Metal										
	Ag	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Water Quality	a	-	77	126	117	91	a	107	99	a	109
	a	98	77	114	117	86	a	107	101	a	109
	-	-	-	103	-	-	-	-	-	-	-
	-	-	-	107	-	-	-	-	-	-	-
Tracer Samples	-	-	-	-	121	131	-	-	96	-	104
	-	-	-	-	115	109	-	-	89	-	97

[a]CASS-1 is not certified for these elements.

TABLE A-6. QUALITY CONTROL RESULTS FOR TOTAL SUSPENDED SOLIDS ANALYSIS.

Sample Type	Quality Control Parameter	Units	Result
TSS	Blank, Field	mg	0.03
	Blank, Field	mg	0.16
TSS	Replicate	%RPD	23 @ 1.0 mg/L
	Replicate	%RPD	12 @ 7.8 mg/L
	Replicate	%RPD	34 @ 2.3 mg/L

TABLE A-7. QUALITY CONTROL RESULTS FOR PARTICULATE METALS ANALYSIS.

		Metal					
Parameter	Units	Cd	Cu	Fe	Ni	Pb	Zn
Field	ng	<1.1	<4.7	240	<3.3	12.2	524
Blank	ng	2.8	<4.7	120	6.3	6.7	768
Replicate[a]	%RPD	31	28	166	40	57	24

[a]Plume DB-10, 4.5 h after disposal.

TABLE A-8. METHOD DETECTION LIMITS OF ORGANIC COMPOUNDS FROM 100-L SAMPLES DURING THE 106-MILE SITE SURVEY, MARCH 1987.

Analyte	Detection Limit (ng/L)
Cl_2(8)	0.09
Cl_3(18)	0.03
Cl_3(28)	0.07
Heptachlor	0.05
Cl_4(52)	0.03
Aldrin	0.08
Cl_4(44)	0.04
Cl_4(66)	0.06
Endolsulfan I	0.08
Dieldrin	0.11
p,p' DDE	0.12
Endrin	0.11
Endolsulfan II	0.10
Cl_5(101)	0.04
p,p' DDD	0.15
Cl_6(153)	0.04
Cl_5(105)	0.17
p,p' DDT	0.18
Cl_6(138)	0.06
Cl_7(187)	0.12
Cl_6(128)	0.19
Cl_7(180)	0.01
Cl_7(170)	0.02
Cl_8(195)	0.01
Cl_9(206)	0.01

TABLE A-9. FIELD RECOVERIES OF DECACHLOROBIPHENYL.

Plume or Event	Depth (m)	Rep. No.	Time After T=0 (h)	Percent Recovery
BG-1	65	1		28.1
BG-1	65	2		39.2[a]
BG-2	16	1		31.5
BG-2	16	2		32.7
DB-13[b]	5	1		12.3
DB-13[b]	5	2		27.5
DB-14	4	1		53.0
DB-14	4	2		36.3
DB-15	2	1		36.8
DB-15	2	2		14.1

[a]Mean of two analytical replicates.

[b]Sample filtered prior to extraction.

TABLE A-10. RESULTS OF BLANK SPIKE ANALYSIS, ORGANIC COMPOUNDS.

Analyte	Percent Recovery Rep. 1	Percent Recovery Rep. 2
Pesticides		
Heptachlor	117	115
Aldrin	374	118
Endolsulfan I	NA	NA
Dieldrin	124	139
p,p' DDE	140	121
Endrin	134	121
Endolsulfan II	NA	NA
p,p' DDD	126	158
p,p' DDT	136	149
PCBs		
Cl_2(8)	35	22
Cl_3(18)	98	102
Cl_3(28)	110	113
Cl_4(52)	102	97
Cl_4(44)	113	100
Cl_4(66)	109	104
Cl_5(101)	91	84
Cl_6(153)	111	103
Cl_5(105)	125	104
Cl_6(138)	113	109
Cl_7(187)	94	92
Cl_6(128)	118	101
Cl_7(180)	110	109
Cl_7(170)	140	122
Cl_8(195)	119	111
Cl_9(206)	91	113

TABLE A-11. RESULTS OF REPLICATE ANALYSIS OF EXTRACTED SAMPLES. SAMPLE WAS COLLECTED AT STATION BG-1, 65 m.

	Analyte	Analytical Result (ng/L)		Percent Difference
		Rep. 1	Rep. 2	
Pesticides				
	Heptachlor	0.135	0.136	0.74
	Aldrin	NA	NA	
	Endolsulfan I	0.215	0.219	1.86
	Dieldrin	NA	NA	
	p,p' DDE	NA	NA	
	Endrin	AN	NA	
	Endolsulfan II	NA	NA	
	p,p' DDD	NA	NA	
	p,p' DDT	NA	NA	
PCBs				
	Cl_2(8)	0.297	0.301	1.35
	Cl_3(18)	0.291	0.317	8.93
	Cl_3(28)	NA	NA	
	Cl_4(52)	NA	NA	
	Cl_4(44)	NA	NA	
	Cl_4(66)	NA	NA	
	Cl_5(101)	NA	NA	
	Cl_6(153)	NA	NA	
	Cl_5(105)	NA	NA	
	Cl_6(138)	0.088	0.088	0.0
	Cl_7(187)	NA	NA	
	Cl_6(128)	NA	NA	
	Cl_7(180)	NA	NA	
	Cl_7(170)	NA	NA	
	Cl_8(195)	NA	NA	
	Cl_9(206)	NA	NA	
	DBOFB	105	104	

APPENDIX B

SUMMARY OF BACKGROUND STATIONS DATA AT THE 106-MILE SITE
MARCH 1988

TABLE B-1. TOTAL SUSPENDED SOLIDS, TURBIDITY, AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED IN BACKGROUND WATER DURING THE MARCH 1988 106-MILE SITE SURVEY.

Event	Depth (m)	Sample Replicate	Time	Time After Disposal (h)	TSS (mg/L)	Light Transmit (%)	Beam Attenuation (m^{-1})
BG1	5	1	0857	NA	0.66	83.3	0.731
	5	2	0857	NA	0.70	83.3	0.731
	60	1	0822	NA	0.49	85.5	0.627
	60	2	0822	NA	9.32[a]	85.5	0.627
	98	1	0844	NA	0.80	87.4	0.539
BG2	6	1	1225	NA	0.36	83.1	0.453
	5	2	1245	NA	0.38	83.4	0.439
	48	1	1339	NA	0.46	85.2	0.641
	47	2	1350	NA	0.39	85.2	0.641

[a]Result is inconsistent with other samples and is likely due to sample processing.

TABLE B-2. *C. perfringens* ENUMERATION IN SAMPLES COLLECTED FROM BACKGROUND WATERS DURING THE MARCH 1988 106-MILE SITE SURVEY.

Plume	Depth	Counts per 100 mL[a] Repl. 1	Repl. 2	Mean[b]
Background 3-2-88	5	0	0	0
	60	0	0	0
	98	0	0	0
Background 3-3-88	5	0	0	0
	48	0	0	0

[a]Colonies were enumerated following APHA guidelines for "Microbial Analysis of Seawater and Marine Organisms". TNTC indicates that the colonies were too numerous to count.

[b]Mean derived from a single count.

TABLE B-3. SUMMARY OF TRACE METAL CONCENTRATIONS FOR UNFILTERED WATER BACKGROUND SAMPLES COLLECTED DURING THE MARCH 1988 106-MILE SITE SURVEY.

Station	Depth m	Rep	Time (h)	As	Ag	Cd[a]	Cu	Cr	Fe[a]	Ni	Pb	Se	Zn[a]	Hg
				µg/L										ng/L
BG1	5	1	NA				1.68		6.03		0.643		3.80	
BG1	5	2	NA				1.09		4.53		3.851		1.30	
BG1	60	1	NA	1.373	0.0022	0.023	0.25	0.13	2.58	0.273	0.109	<0.036	1.22	7.6
BG1	60	2	NA	1.519	0.0018	0.022	0.35	0.15	2.47	0.257	0.137	<0.036	1.37	7.9
BG1	98	1	NA				6.41		41.11		3.604		16.06	
BG2	6	1	NA	1.335	0.044	0.023	0.21	0.15	0.38	0.288	0.092	<0.037	0.42	3.4
BG2	5	2	NA	1.217	0.0026	0.024	0.24	0.14	0.27	0.279	0.056	<0.036	0.43	8.3
BG2	48	1	NA	0.934	0.0021	0.021	0.19	0.14	0.36	0.297	0.345	<0.038	0.22	4.9
BG2	47	2	NA	1.434	0.0028	0.018	0.22	0.13	1.68	0.256	0.134	<0.037	0.25	3.7

[a]Blank corrected.

TABLE B-4. SUMMARY OF PARTICULATE METAL RESULTS FROM SAMPLES COLLECTED FROM THE BACKGROUND WATERS DURING THE MARCH 1988 106-MILE SITE SURVEY. UNITS ARE IN µg/L.

Station	Depth (m)	Rep	Time (h)	Cd	Cu	Fe	Ni	Pb	Zn
BG1	5	1	NA	0.0046	0.137	2.66	0.021	0.059	0.99
BG1	5	2	NA	0.0043	0.065	1.99	0.028	0.066	1.63
BG1	60	1	NA	0.0054	0.028	1.915	0.007	0.042	0.25
BG1	60	2	NA	0.0121	0.111	8.53	0.034	0.081	0.87
BG1	98	1	NA	0.0058	0.38	21.08	0.017	0.826	1.05
BG2	6	1	NA	0.0069	0.015	0.8	0.017	0.040	0.61
BG2	5	2	NA	0.0050	0.014	0.45	0.005	0.048	1.15
BG2	48	1	NA	0.0056	0.015	0.72	<.0047	0.034	0.59
BG2	47	2	NA	0.0046	0.023	1.42	<.0044	0.047	1.41

TABLE B-5. BACKGROUND WATER QUALITY PESTICIDE ANALYSIS, 106-MILE SITE, MARCH 1988. (NO OTHER PESTICIDES WERE FOUND IN THE BACKGROUND SAMPLES.)

Station	Depth (m)	Rep	Pesticide	Concentration (ng/L)
BG-1	65	1	Endosulfan I	0.15
BG-2	16	12	Dieldrin	0.60

TABLE B-6. BACKGROUND WATER QUALITY PCB ANALYSIS STATIONS FOR THE 106-MILE SITE SURVEY, MARCH 1988. (NO OTHER PCBs WERE FOUND IN THE BACKGROUND SAMPLES.)

Station	Depth (m)	Rep	PCB	Concentration (ng/L)
BG-1	65	1	Cl_6(138)	0.254
BG-2	16	2	Cl_7(180)	0.406

APPENDIX C

SUMMARY OF LABORATORY DATA FROM PLUMES DB10, DB11, DB13, DB14, AND DB15 SURVEYED AT THE 106-MILE SITE IN MARCH 1988

TABLE C-1. TOTAL SUSPENDED SOLIDS, TURBIDITY, AND BEAM ATTENUATION RESULTS FOR DISCRETE SAMPLES COLLECTED DURING DUMPING EVENTS, MARCH 1988 106-MILE SITE SURVEY.

Event	Depth (m)	Sample Replicate	Time	Time After Disposal (h)	TSS (mg/L)	Light Transmit (%)	Beam Attenuation (m^{-1})
DB10	1	1	1217	0.1	8.00	19.4	6.243
	1	2	1217	0.1	7.50	19.4	6.243
	4.5	1	1635	4.3	1.13	78.4	0.913
	4.5	1	1635	4.3	0.90	78.4	0.913
DB11	2.5	1	2012	0	1.09	NA	
	2.5	2	2012	0	1.71	NA	
DB13	5	1	2007	0	1.17	76.5	1.072
	1	1	2025	0.3	18.5	0.2	24.193
	5	1	2115	1.2	16.9	2.5	14.756
	5	1	2119	1.2	12.1	10.7	8.94
	3	1	2141	1.6	8.00	11	8.829
	0	1	2137	1.5	9.12	14	7.864
	0	2	2137	1.5	26.6	14	7.864
	0	1	2151	1.8	8.23	57.7	2.2
	0	2	2151	1.8	7.33	57.7	2.2
	0	1	2157	1.9	1.84	47.5	2.978
	0	2	2157	1.9	2.16	47.5	2.978
	0	1	2220	2.3	1.93	NA	NA
	0	2	2220	2.3	2.73	NA	NA
DB14	2	1	0719	0	5.68	NA	NA
	2	2	0721	0	1.26	NA	NA
	1	1	0737	0.3	8.46	NA	NA
	2	1	0737	0.3	2.00	NA	NA
	3	1	0821	1	0.92	NA	NA
	4	1	0821	1	0.29	NA	NA
DB15	1	1	1103	0	2.10	NA	NA
	2	1	1103	0	0.74	NA	NA
	0.5	1	1119	0.3	1.41	NA	NA
	1.5	1	1119	0.3	3.83	NA	NA
	1.5	1	1133	0.5	0.58	NA	NA
	2.5	1	1133	0.5	2.97	NA	NA

TABLE C-2. *C. perfringens* ENUMERATION IN DISCRETE SAMPLES COLLECTED DURING DUMPING EVENTS, MARCH 1988 106-MILE SITE SURVEY.

Plume	Time (h)	Depth	Counts per 100 mL		
			Repl. 1	Repl. 2	Mean[a]
DB10	0.08	1	420	420	420
	4.3	5	34		34
DB11	0.00	2.5	2	5	3.5
DB13	0.00	5	0	-	0
	0.32	1	0	-	0
	0.90	5	0	-	0
	1.15	5	0	-	0
	1.22	5	0	-	0
	1.58	3.1	0	-	0
DB14	0	2	TNTC	TNTC	TNTC
	0.30	1-2	67	55	61
	1.00	3-4	40	83	62
DB15	0	1-2	1200	729	964
	0.27	0.5-1.5	388	729	558
	0.50	1.5-2.5	47	57	52

Colonies were enumerated following APHA guidelines for "Microbial Analysis of Seawater and Marine Organisms." TNTC indicates that the colonies were too numerous to count.

[a]Mean derived from a single count.

TABLE C-3. SUMMARY OF TRACE METAL RESULTS FOR WHOLE WATER SAMPLES COLLECTED DURING DUMPING EVENTS, MARCH 1988 106-MILE SITE SURVEY.

Plume	Sample Depth (m)	Rep	Time After T=0 h	As	Ag	Cd[a]	Cu	Cr	Fe[a]	Ni	Pb	Se	Zn[a]	Hg
				μg/L										ng/L
DB10	1	1	0.1	1.44	0.157	0.251	15.11	7.30	153.3	1.723	10.602	<0.037	14.76	40.5
DB10	1	2	0.1	1.41	0.149	0.323	19.51	9.09	190.9	2.395	14.091	<0.036	17.23	9.1
DB10	4.5	1	4.3	1.31	0.053[b]	0.041[b]	1.56[b]	0.63	14.0[b]	0.435[b]	1.036[b]	<0.038[b]	1.41[c]	6.6
DB11	2.5	1	0	1.23	0.0069	0.033	0.36	0.38[b]	2.96	0.322	0.396	<0.038	1.25	5.6
DB11	2.5	2	0	0.82	0.0083[b]	0.034	0.40	0.29	2.97	0.336	0.378	<0.038	1.51	4.7
DB13	5	1	0	1.37	0.010	0.036	0.39	0.28	3.37	0.323	0.807	0.112	1.21	19.2
DB13	1	1	0.3	1.29	0.096	0.502	7.48	11.14	117.1	1.677	34.462	<0.052	35.73	88.3
DB13	5	1	1.2				6.83		93.3		30.98		31.50	
DB13	5	1	1.2				3.34[b]		41.9[b]		16.08[b]		15.29[b]	
DB13	3	1	1.6				2.90		39.4		13.53		12.46	
DB14	2	1	0	2.03	0.144	0.133	12.43	2.48	154.2	1.137	9.660	<0.039	19.48	29.8
DB14	2	2	0	1.72	0.041	0.040	1.73	0.38	22.3	0.343	1.455	<0.038	2.95	4.8
DB14	1	1	0.3				0.60		11.3		0.386		28.81	
DB14	2	1	0.3				0.39		3.2		0.353		2.51	
DB14	3	1	1				0.36		2.5		0.354		1.09	
DB14	4	1	1				0.43		3.2		0.270		1.44	
DB15	1	1	0	1.90	0.107	0.056	4.86	0.47	50.6	0.884	2.132	<0.038	6.35	10.2
DB15	2	1	0	1.48	0.096	0.048	1.86	0.39	24.6	0.378	0.435	<0.040	3.63	8.4
DB15	0.5	1	0.3				1.34		18.2		0.386		2.88	
DB15	1.5	1	0.3				0.946		13.0		0.286		1.87	
DB15	1.5	1	0.5				0.340		1.33		0.150		2.82	
DB15	2.5	1	0.5				0.296		1.36		0.089		1.38	

[a]Blank corrected.

[b]Mean of replicate analysis.

[c]Duplicate rejected due to suspect contamination.

TABLE C-4. SUMMARY OF PARTICULATE METAL RESULTS FROM SAMPLES COLLECTED DURING DUMPING EVENTS, MARCH 1988 106-MILE SITE SURVEY.

Station	Depth (m)	Rep	Time (h)	Cd (µg/L)	Cu (µg/L)	Fe (µg/L)	Ni (µg/L)	Pb (µg/L)	Zn (µg/L)
DB10	1	1	0.1	0.2333	13.47	118.4	1.182	9.600	13.83
DB10	1	2	0.1	0.2575	14.8	123.75	1.025	10.350	16.50
DB10	4.5	1	4.3	0.0246	1.03	7.69	0.152	0.690	1.53
DB11	2.5	1	0	0.0124	0.15	3.68	0.055	0.290	5.06
DB11	2.5	2	0	0.0139	0.18	3.35	0.11	0.240	1.53
DB13	5	1	0	0.012	0.169	2.44	0.02	0.354	1.28
DB13	1	1	0.3	0.500	12.83	123.08	1.177	37.51	44.61
DB13	5	1	1.2	0.466	12.94	111.89	1.109	36.97	38.17
DB13	5	1	1.2	0.174	4.19	40.47	0.364	12.43	14.08
DB13	3.1	1	1.6	0.184	4.78	43.24	0.361	13.17	14.16
DB14	2	1	0	0.076	6.5	83.04	0.318	5.30	12.48
DB14	2	2	0	0.017	1.4	16.45	0.071	1.09	3.34
DB14	1	1	0.3	0.0081	0.19	6.84	0.031	0.18	1.41
DB14	2	1	0.3	0.051	0.097	3.63	0.044	0.18	8.95
DB14	3	1	1	0.0088	0.11	2.3	0.014	0.10	0.73
DB14	4	1	1	0.0075	0.12	2.35	0.023	0.12	0.42
DB15	1	1	0	0.050	2.05	24.55	0.122	0.38	5.00
DB15	2	1	0	0.041	1.7	21.3	0.087	0.38	4.43
DB15	0.5	1	0.3	0.025	0.73	12.46	0.048	0.24	3.37
DB15	1.5	1	0.3	0.0085	0.43	5.06	0.027	0.11	1.08
DB15	1.5	1	0.5	0.0073	0.094	1.18	0.017	0.050	0.50
DB15	2.5	1	0.5	0.0099	0.11	1.38	0.025	0.051	0.44

TABLE C-5. SUMMARY OF PESTICIDE RESULTS FOR WHOLE WATER SAMPLES COLLECTED DURING DUMPING EVENTS, MARCH 1988 106-MILE SITE SURVEY.

Plume	Sample Depth (m)	Rep	Time After Disposal (h)	Dieldrin (ng/L)	p,p'DDE (ng/L)
DB13	5	1	0	ND	ND
DB13	5	2	0	0.31	ND
DB14	4	1	0	0.124	0.267
DB14	4	1	0	0.125	0.223
DB15	2	1	0	0.119	ND
DB15	2	2	0	0.104	ND

TABLE C-6. SUMMARY OF PCB RESULTS (in ng/L) FOR WATER SAMPLES COLLECTED DURING DUMPING EVENTS, MARCH 1988 106-MILE SITE SURVEY.

	Sample and Location					
PCB Isomer	DB-13[a] Rep. 1 5 m	DB-13[a] Rep. 2 5 m	DB-13[b] Rep. 1 5 m	DB-13[b] Rep. 2 5 m	DB-14 Rep. 1 4 m	DB-14 Rep. 2 4 m
Cl_3(28)	0.272					
Cl_4(52)	0.027		1.224	0.682		
Cl_4(44)			0.866	0.490		
Cl_4(66)	0.770					
Cl_5(101)			1.069	0.652	0.140	
Cl_6(153)					0.208	0.169
Cl_6(138)	0.119				0.239	
Cl_6(128)			0.101	0.067		
Cl_7(180)		0.075	0.377	0.303	0.194	0.141
Cl_7(170)			0.523	0.386		0.152
Total, dissolved	1.19	0.075			0.78	0.46
Total, particulate	-	-	4.16	2.58	-	-

[a]Dissolved fraction of this sample.
[b]Particulate fraction of this sample.